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WORKLOAD AND THE CERTIFICATION OF HELICOPTERS FOR IFR OPERATION

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June 1979

FINAL REPORT

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16. Abstract

A review was made of the Interim Criteria, Federal Aviation Regulations, Advisory Circulars and other pertinent Documents associated with certification of Helicopters for instrument flight. A review of publications pertaining to workload definitions and evaluation, applicable to IFR helicopter operations was accomplished. The report identifies the role of aircrew workload in the IFR certification process and develops a rationale to allow determination of that portion of a pilot's attention and effort available for aircraft control. Performance objectives for required maneuvers are delineated and the interdependence of performance and workload is identified. Workload/performance implications for single and dual pilot IFR operations are reviewed. A series of flight maneuver patterns for use as IFR certification assessment tools is developed. A flying qualities workload evaluation scheme is offered for use in the FAA certification process for IFR approval of helicopters.

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PREFACE

The study described in this report was sponsored by the Systems Research and Development Service (SRDS), Federal Aviation Administration, U.S. Department of Transportation under Contract Number DOT-FA77WA-3966. Mr. Thomas C. West (ARD-530) served as technical monitor and engineer for the Systems Research and Development Service. The authors wish to express their appreciation to the branches and sections of the Federal Aviation Administration; namely, the Aircraft Flight Safety Branch of SRDS (ARD-530) and the Southwest Regional Headquarters at Fort Worth, Texas (ASW) for their cooperation in this research.

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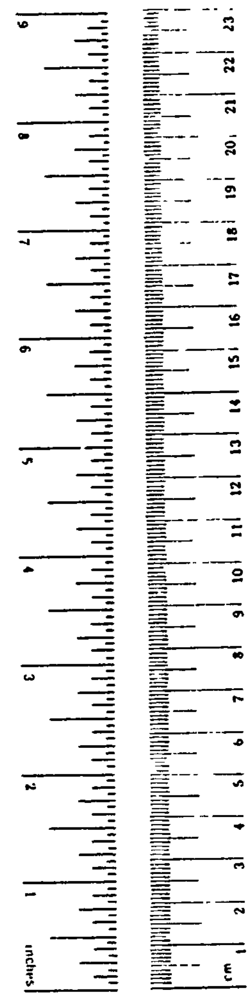
METRIC CONVERSION FACTORS

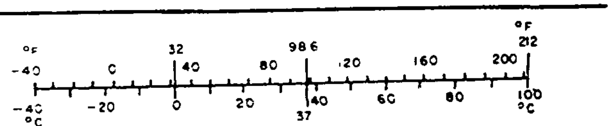
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ABBREVIATIONS

AC	Advisory Circular
A/C	Aircraft
ADF	Automatic Direction Finder
ADI	Attitude Director Indicator
AFCS	Automated Flight Control System
AGL	Above Ground Level
AIM	Airman's Information Manual
AMC	Aircrew Manning Configuration
AP	Autopilot
ARU	Attitude Retention Unit
ASR	Airport Surveillance Radar
ASW	Anti-Submarine Warfare
ATC	Air Traffic Control
BC	Back Course
CAT	Category
COMM	Communication
CRT	Cathode Ray Tube
DF	Direction Finder
DH	Decision Height
DME	UHF Standard (TACAN Compatible) Distance Measuring Equipment
EFC	Expected Further Clearance
FAA	Federal Aviation Administration
FAC	Final Approach Course
FAF	Final Approach Fix
FAR	Federal Aviation Regulations
FD	Flight Director
FM	Fan Marker
FSS	Flight Service Station
GNS	Global Navigation System
GS	Glideslope
IAF	Initial Approach Fix
IF	Intermediate Approach Fix
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IMLS	Interim Microwave Landing System
ITO	Instrument Takeoff
LF	Low Frequency
LOC	Localizer
LOM	Compass Locator at Outer Marker ILS
MAP	Missed Approach Point
MDA	Minimum Descent Altitude
MLS	Microwave Landing System
MM	Middle Marker (ILS)
MSL	Mean Sea Level
NAV	Navigation

NDB	Non-Directional Radio Beacon
NM	Nautical Miles
NPH	Non-Precision (Approach) Helicopter
OBS	Omnibearing Selector
OM	Outer Marker (ILS)
PAR	Precision Approach Radar
PIC	Pilot-in-Command
RNAV	Area Navigation
RVR	Runway Visual Range
SAS	Stability Augmentation System
SCAS	Stability and Control Augmentation System
SFAR	Special Federal Aviation Regulation
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
STC	Supplemental Type Certificate
SVFR	Special Visual Flight Rules
TACAN	UHF Navigational Facility Omni-Directional Course and Distance Information
TC	Type Certification
TCA	Terminal Control Area
TERPS	Terminal Instrument Procedures
UHF	Ultra High Frequency
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Rules
VHF	Very High Frequency
VLF	Very Low Frequency
VMC	Visual Meteorological Conditions
VOR	VHF Omni-Directional Radio Range
VORTAC	Combined VOR and TACAN System
VOT	a VOR Receiver Testing Facility

SECTION 1

INTRODUCTION

GENERAL

This report covers the efforts of follow-on work pursuant to an earlier study of airworthiness standards and IFR certification processes for helicopters (Reference 1).

Reference 1 reviewed the "current" Interim Criteria (Reference 2), Federal Aviation Regulations, Advisory Circulars and other pertinent reports and documents associated with the certification of helicopters for instrument flight. It also identified specific airworthiness requirements for helicopters operating in instrument meteorological conditions with special attention given to aircrew manning configurations, pilot workload, ability to trim, static stability, dynamic stability, handling qualities, analysis of time history data and documentation procedures, augmentation systems, autopilots and a review of certain flight test techniques.

In the course of the analyses performed in Reference 1, it became apparent that during the IFR certification process, considerable importance is placed on the determination of satisfactory workload level for the minimum aircrew for IFR flight in a helicopter. The apparent need for a workload appraisal or evaluation scheme manifested itself primarily in the recent, numerous one-pilot aircrew manning level approvals. It was determined that there was a requirement to establish a workload evaluation scheme that was related to flying qualities suitability and was applicable to the IFR certification process for helicopters.

Some of the critical subject areas identified for additional study were: the development of a series of flight patterns that could be used to standardize maneuver objectives for use in the certification process; identification of performance objectives; determination in relative terms of that portion of a pilot's total attention which can be applied to the flight control task; development of a flying qualities workload rationale and definition scheme which would allow workload to be stated in meaningful terms for evaluation pilots. Using the results of studies addressing the above issues, a flying qualities workload evaluation system would be established which could be applicable to the FAA certification process for helicopters.

The efforts to analyze those areas are addressed in this report.

SECTION 2

THE ROLE OF PILOT WORKLOAD IN THE IFR CERTIFICATION PROCESS

INTRODUCTION

This section discusses the role of pilot workload in the IFR certification process, highlighting the differences between one and two-pilot operations. It further defines workload as being of two types: flight control tasks and auxiliary tasks, and describes their relationship as it applies to helicopter certifications. Examples of two critical IFR flight phases that appear to be of prime importance in the assessment of the minimum required flight crew and satisfactory workload level are included.

GENERAL

An analysis of recently certified IFR helicopters was conducted and it was determined that a helicopter, with a given aircrew manning level, instrument display and avionics package, will not receive an IFR certification if the examining pilot determines that the workload level on the minimum required aircrew is too high or demanding even though the man/machine system adequately and fully complies with the Interim Criteria, FAR, etc., in all other respects. This appears to be especially true for one-pilot certifications. For example, for one-pilot certifications, if the total workload level is too high, some type of workload relief (in the form of stability augmentation systems, and/or automatic stability equipment, and/or better display systems or avionics) is provided to the lone pilot to reduce the high workload. Because of the requirements of the certification process and since the workload appraisal is fundamentally important, the examining pilots must carefully judge the workload level (pilot's effort and attention required in the performance of all flight phases) to assess whether it is acceptable or not. Given this situation, it appears that, in the past, examining pilots have established, at least in their own minds, acceptability criteria for workload level rating and judging of compliance with the Federal Aviation Regulations and Interim Criteria. Since the judgment methods used by the FAA examiners are mostly informal and sometimes personal systems, and are not delineated as in the familiar Cooper-Harper schemes (Reference 3), the precise definitions and methodology as related to the workload certification task are difficult to pin down and categorize. Obviously, such a system can be successfully utilized as long as individual bias is suppressed, and the participants generally agree to certain ground rules and norms, and coordinate them properly among all the various affected agencies and companies. As an operating practice, an informal, unstructured workload level rating system can be burdensome when the many variables in the problem and the different certification goals of all interested parties are considered.

In order for the FAA to develop useful and meaningful criteria for IFR approvals, the workload objectives for each certification goal need to be clearly established. These workload objectives must be defined in a way that will permit general correlation to pilot/vehicle handling qualities factors and IFR certification goals (e.g. stability and control, display systems, task, aircrew manning level etc.).

PILOT WORKLOAD CRITERIA AND TERMINOLOGY

The subject of pilot workload and establishment of the minimum required flight crew sufficient for safe operation is addressed in both the Federal Aviation Regulations and the Interim Criteria for certification of helicopters for IFR operations (Reference 2). In PARTS 27 and 29 of the Federal Aviation Regulations: Airworthiness Standards for Normal Category Rotorcraft and Transport Category Rotorcraft under Subpart G, Operating Limitations and Information, Sections 27.1523 and 29.1523, the following pertinent statements are made under the subheading of MINIMUM FLIGHT CREW:

"The minimum flight crew must be established so that it is sufficient for safe operation, considering -

(a) The workload on individual crewmembers;

(b) The accessibility and ease of operation of necessary controls by the appropriate crewmember ..."

Also, several phrases and paragraphs in the current Interim Criteria relate to the subject area of pilot workload, namely:

"(j) IFR Flight. The rotorcraft must be flown in the air traffic control system under actual IFR day and night conditions for a period of at least five hours. The items evaluated during this period include:

(1) Ability to operate the rotorcraft satisfactorily under IFR conditions in the air traffic control system without undue pilot fatigue or exceptional pilot skill or alertness.

(5) In-flight IFR workload demands on the minimum required flight crew.

(6) Handling of the rotorcraft in rough air turbulence."

Other sections of FAR 27 and 29 address the workload issue more indirectly and with special regard to failures. One example of this is given under FAR 27 and 29, Subpart B, Flight Characteristics, Section 27.141 subparagraph (b) excerpted as:

"(b) Be able to maintain any required flight condition and make a smooth transition from any flight condition to any other flight condition without exceptional piloting skill, alertness, or strength, and without danger of exceeding the limit load factor under any operating condition probable for the type, including -

(1) Sudden failure of one engine, for multi-engine rotorcraft meeting transport category A engine isolation requirements; and

(2) Sudden, complete power failure, for other rotorcraft; and

(c) Have any additional characteristics required for night or instrument operation, if certification for those kinds of operation is requested."

Federal Aviation Regulations, Part 25, Airworthiness Standards: Transport Category Airplanes is interesting in that, in addition to mentioning the need to establish minimum flight crew and workload on individual crew members in Section 25.1523, it makes reference to an Appendix D in that Part, namely:

"Criteria for determining minimum flight crew. The following are considered by the FAA in determining the minimum flight crew under 25.1523:

a. Basic workload functions. The following basic workload functions are considered:

(1) Flight path control.

(2) Collision avoidance.

(3) Navigation.

(4) Communications.

(5) Operation and monitoring of aircraft engines and systems.

(6) Command decisions.

b. Workload factors. The following workload factors are considered significant when analyzing and demonstrating workload for minimum flight crew determination:

(1) The accessibility, ease, and simplicity of operation of all necessary flight, power, and equipment controls, including emergency fuel shutoff valves, electrical controls, electronic controls, pressurization system controls, and engine controls.

(2) The accessability and conspicuity of all necessary instruments and failure warning devices such as fire warning, electrical system malfunction, and other failure or caution indicators. The extent to which such instruments or devices direct the proper corrective action is also considered.

(3) The number, urgency, and complexity of operating procedures with particular consideration given to the specific fuel management schedule imposed by center of gravity, structural or other considerations of an airworthiness nature, and to the ability of each engine to operate at all times from a single tank or source which is automatically replenished if fuel is also stored in other tanks.

(4) The degree and duration of concentrated mental and physical effort involved in normal operation and in diagnosing and coping with malfunctions and emergencies.

(5) The extent of required monitoring of the fuel, hydraulic, pressurization, electrical, electronic, deicing, and other systems while enroute.

(6) The actions requiring a crew member to be unavailable at his assigned duty station, including: observation of systems, emergency operation of any control, and emergencies in any compartment.

(7) The degree of automation provided in the aircraft systems to afford (after failures or malfunctions) automatic crossover or isolation of difficulties to minimize the need for flight crew action to guard against loss of hydraulic or electric power to flight controls or to other essential systems.

(8) The communications and navigation workload.

(9) The possibility of increased workload associated with any emergency that may lead to other emergencies.

(10) Incapacitation of a flight crewmember whenever the applicable operating rule requires a minimum flight crew of at least two pilots.

(c) Kind of operation authorized. The determination of the kind of operation authorized requires consideration of the operating rules under which the airplane will be operated. Unless an applicant desires approval for a more limited kind of operation, it is assumed that each airplane certificated under this Part will operate under IFR conditions."

It is noted that Appendix D of FAR PART 25 lists some basic workload functions for the pilot. The six functions listed under (a) of that Appendix can be divided into two common categories, flight control tasks and auxiliary (non-flight control) tasks. Flight Path Control is definitely a pilot flight control task whereas Collision Avoidance under IMC and Instrument Flight Rules is a shared task within the NAS and ATC system. The remaining four basic workload functions listed in Appendix D (PART 25); Navigation, Communications, Operation and Monitoring of Aircraft Engines and Systems and Command Decisions may be categorized as auxiliary tasks. Paragraph (b) of Appendix D (PART 25) stresses the fact that workload level must be analyzed carefully for the minimum required flight crew level determination. Although this particular regulation applies to airplanes, important and equivalent workload factors should exist for helicopters. Also, paragraph (c) of Appendix D (PART 25) states that it is assumed that each airplane certificated under this Part will operate under IFR conditions.

Important early research and analyses on the fundamentals of flying qualities, pilot workload, and performance have been accomplished by NASA Langley and the CALSPAN Corporation of Buffalo, NY and are summarized in Reference 3. In order to constrain the terminology and understand the relationships of the variables used in the judgment of flying qualities and workload/performance factors, certain well recognized definitions and flight phase descriptions are provided in Appendix A of this Report. Also, a schematic is shown in Figure 2-1 that depicts the interplay between the various pilot control loops and handling qualities factors. Note that Pilot Tasks are divided into two categories:

1. Flight Control Tasks.
2. Auxiliary Tasks (ATC/COMM/NAV, etc.).

The input arrows and feedback loops to the pilot (Pilot Box on Figure 2-1) show the workload paths for the pilot in the achievement and performance of a task. Both the graph (Figure 2-1) and Appendix A provide vital and fundamental information needed for the discussions on pilot workload and task performance objectives covered in later sections of this Report. The definitions of Workload and Task in Appendix A are especially important. They are:

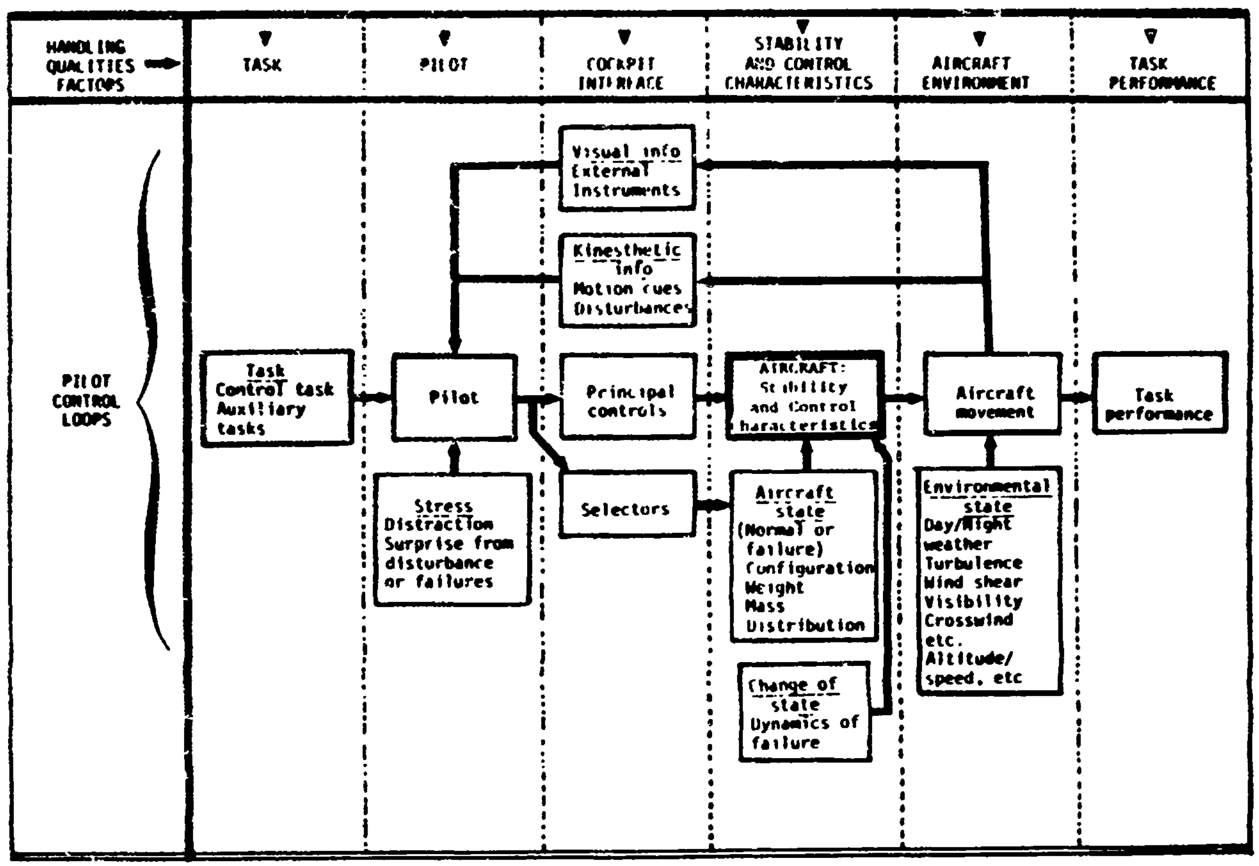


Figure 2-1. Handling Qualities Factors versus Pilot Control Loops

- TASK - The actual work assigned a pilot to be performed in completion of or as representative of a designated flight segment.

  - Control - That part of a task which requires continuing actuation of the principal controls and use of the selectors as required.

  - Auxiliary - That part of a task which involves the pilot in actions other than direct control of the aircraft.

  Examples: Navigation, communication monitoring, selection of systems, and ATC interaction.

- WORKLOAD - The integrated physical and mental effort required to perform a specified piloting task.

  - Physical - The effort expended by the pilot in moving or imposing forces on the controls during a specified piloting task.

  - Mental workload is at present not amenable to quantitative analysis by other than pilot evaluation, or indirect methods using physical workload (input) and the task performance measurements. An example would be the improvement associated with flight-director type displays which reduce the mental compensation normally required of the pilot.

(NOTE: No attempt is made in this report to separate workload into the two divisions related above -- Physical/Mental. Only the combined meaning of workload is utilized in this study namely, the integrated physical and mental effort and attention required to perform a specified task. Research and analyses have been conducted (with varying degrees of success) on attempts to separate the efforts but this subject area is not addressed in this report.

Reference 4 entitled "HELICOPTER PILOT WORKLOAD EVALUATION" is an example of research on factors such as pilot stress and fatigue. The reported work in that reference covers the research accomplished during inflight investigations of short duration operational helicopter missions. The prime objective was to determine the level of pilot stress encountered by evaluating the changes in pilot performance, control activity, and biochemical levels.)

DISCUSSION OF AIRCREW WORKLOAD CAPABILITIES

In Figure 2-2a, the piechart depicts the basic dual pilot case where the total available workload that may be apportioned to the two pilots for those efforts required to conduct an IFR helicopter flight is shown by a left and right half pie representing 100% of each pilot's available workload. The left half pie represents the pilot's 100% available workload and the right half pie represents the copilot's 100% available workload. It is appropriate to presume that the pilot does not ever desire to make available or choose to provide his full 100% workload capability to operate the aircraft in routine flight but deems it necessary to always "hold in reserve" a portion of his total capability to handle emergencies and other unusual or unexpected flight occurrences. In other words, the conduct of the flight should not tax the aircrew to the extent that for the most demanding, non-failed, flight state, the on-board crew is devoting its absolute total workload capability to accomplishing the standard task at hand. It is presumed that an aircrew would not intentionally or repeatedly plan, dispatch, and conduct routine IFR flight operations where the total workload needed to accomplish the flights always required their full, maximum capabilities.

The "reserve" workload portion, whether gained by conscious pre-allocation or by extra natural (adrenaline or whatever) causes is set aside here and so designated in the pilot (left hand) portion so that his desired, normally available workload capacity is only about 85% of his total portion (about 15% earmarked for the reserve). The exact percentages detailed here are not as important as the idea that a pilot desires to hold in reserve some degree of extra workload capability to handle unexpected or unusual flight occurrences.

The definitions or guidelines stated below are offered to aid in understanding other sections of this report related to discussions on workload capability and allocation. A 100 percent workload capability is that amount of workload available that a crew member may use without entering an overload condition. An overload condition is a workload condition where the crew member would soon be operating beyond his error-free tendencies and capacities. If he cannot hand off the extra workload, he starts to forget workload items or chooses to rank them according to the importance of the tasks and neglects or omits those he determines to be of lesser importance. If possible, he will enlist the use of automated or automatic systems to provide workload relief for the overload condition. Reserve workload capability (un-allocated, non-dedicated or "open" workload) is that portion of a crew member's 100 percent capability that is left open or not allocated during routine/non-emergency flight situations. It is that portion of the crew

Pilot and Copilot Available Workload Capability to be Apportioned to Those Duties and Efforts Required to Conduct an IFR Helicopter Flight.

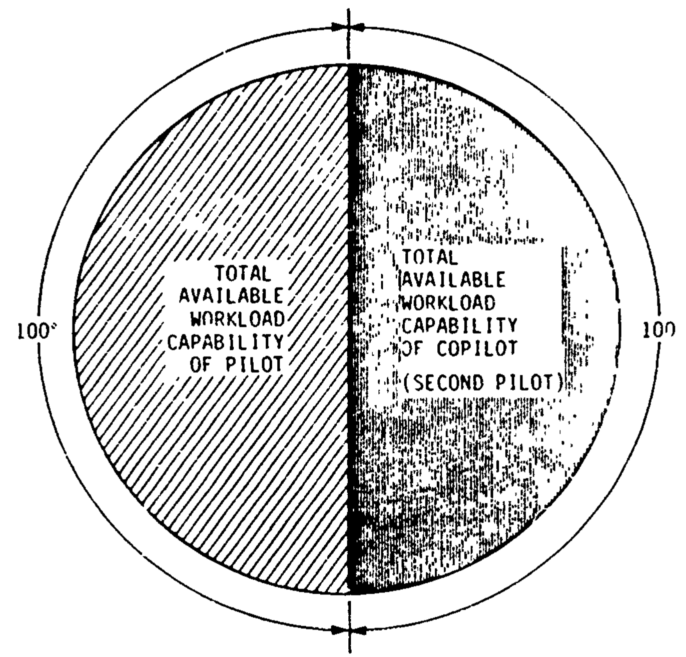


Figure a

Pilot and Copilot Available Workload Capability With Portion of Pilot Workload Pre-allocated for Reserve Workload Capability.

(Cross-hatched Area Shown Earmarked for Reserve Workload of Pilot).

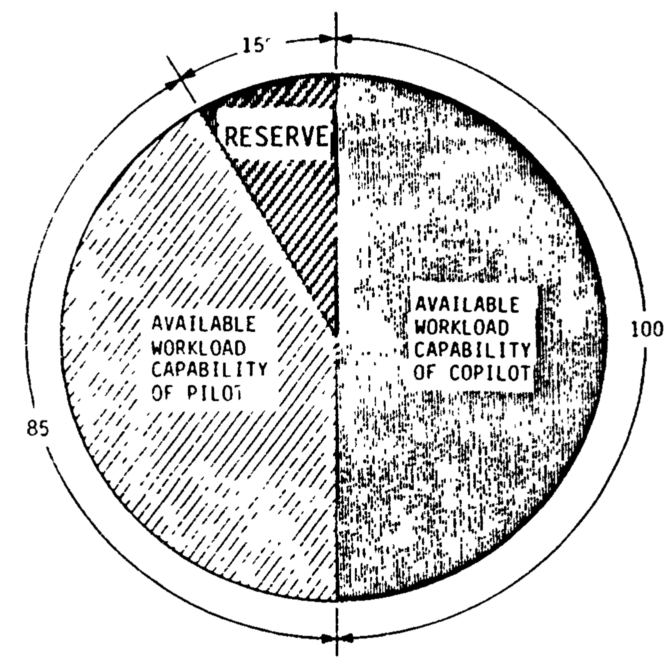


Figure b

Figure 2-2. Depiction of Total Available Workload Capabilities for Two-Pilot Aircrew Manning Levels.

member's 100 percent capability that he holds in reserve to allow for possible non-routine, unexpected and emergency activities or occurrences to be handled without degrading or affecting the achievement of the crew member's personal and standard performance goals.

Since the pilot has the reserve workload capability set aside, it is assumed that the copilot can be worked to 100% of his capacity during routine IFR flight operations, if need be. Therefore, for this illustration in Figure 2-2, in the two-pilot case there is, in terms of a type of workload factor, about a 1.85 total capability, if needed, and in the single-pilot case (copilot not on board) there is, in terms of a workload factor, about 0.85 total capability available, if needed, for standard, non-failed IFR missions (Figure 2-2b).

A great many unresolved issues and techniques exist when attempting to discuss measurements of, or estimate workload level. Several methodologies and techniques such as time-line analyses, computer and theoretical analyses, and operational testing are frequently utilized. One measurement technique and definition that has been used recently for individual task measurement is called the task loading percentage (Reference 5) and is defined as:

$$\text{Task Loading Percentage} = \frac{\text{Time Required for Task (times 100)}}{\text{Time Available for Task}}$$

This methodology is best applied to "overt" tasks such as copying a clearance, running through a checklist, reading a map, system selection or inserting waypoints on an RNAV system. It is essentially inapplicable for "covert" tasks where mental processes, decision making, command and monitoring functions are concerned.

If the Task Loading Percentage exceeds 100, an OVERLOAD situation or condition exists. Reference 5 summarizes some possible consequences of OVERLOAD conditions as:

- The crew member may be able to compensate for the overload by working faster.

- Depending on the type of task, the crew member may defer action on it and accomplish it at a later time, if possible.

- If possible, the crew member may attempt to hand off certain tasks to another crew member.

- If available, the crew member may attempt to use some automatic system or automated avionics to relieve some of the overload.

Some of the aforementioned items related to overloads may be utilized to a point, but they may in turn result in different effects and frequently cause new situations. For example, a pilot may work faster for limited periods of time (5 to 10 minutes for a 115 percent workload, 15 percent overload) at the cost of causing fatigue onset to occur at an earlier time. If the crewmember is very heavily overloaded (125 to 150 percent workloads, 25 to 50 percent overloads, for short times or even 15 percent overload for long times) he may start omitting or neglecting tasks. If the tasks are important and cannot be neglected, he will try to hand them off to another crew member and/or utilize an automatic or automated device for workload relief (if possible).

If the minimum aircrew is required to frequently perform in high workload situations or overload conditions, several consequences are possible (Reference 5):

- Onset of early fatigue for crew members.
- Increased probability of making errors.
- Reduction in so-called "Workload Reserve Capacity".
- Performance decrements may start to occur.
- Reduced probability of flight phase (and mission) completion.
- Possible increase in probability of ATC rules violation and incident or accident occurrence.
- Possible decreased quality and level of safety of flight.

TYPICAL ONE AND TWO PILOT IFR CERTIFICATIONS

In the last several years, a large variety of helicopters, flight control and stabilization systems, avionics, and instrument displays have been involved or utilized in the IFR certification process. Of the nine or ten helicopters certified for IFR flight with either one or two pilot aircrews, several helicopters have been certified for one and two pilot aircrew manning levels depending on installed and operable equipment and systems. An example of a particular helicopter that has been certified for different minimum aircrew manning levels (one-pilot or two-pilot) versus installed and operable equipment and systems is discussed below. According to the flight manual, for certified single-pilot IFR operation, artificial stabilization systems are required. For certified two-pilot IFR operations (using the same basic helicopter) the artificial stabilization systems are not required. The two-pilot IFR certified helicopter may be flown routinely on IFR flights with the artificial stability systems inoperable (or not installed) as long as two fully qualified IFR pilots are on board and two fully equipped flight stations with full controls and instruments are provided.

Typically, the single-pilot IFR certified helicopters may contain an attitude type SAS (or SCAS) system and also provide (for continuous use) the attitude-hold function of an autopilot. The SAS attitude (or SCAS) system usually enhances the stability and control characteristics so that the flying qualities of the helicopter are improved sufficiently (and flight control workload reduced) that the pilot can participate in the performance of the auxiliary tasks required for IFR flight. Frequently, additional flight control workload relief is provided to the pilot by the attitude-hold autopilot. Sometimes a flight director is offered (and required) to mitigate the pilot's workload/performance problems when precision flight is a necessity as in a CAT I, ILS approach.

Although the auxiliary task workload may vary considerably during the course of a flight depending on area traffic density, flight phases, availability of radar control and vectoring, weather conditions, etc., the auxiliary tasks, in general, are fairly predictable and definable. They usually cannot be varied much for a specific case and condition unless the more sophisticated avionics and highly automated subsystems are added to these certified vehicles. Some auxiliary task workload relief could be obtained for the single-pilot with regard to navigation and position location tasks if additional equipment such as pre-programmed multiple waypoint RNAV systems, dual DME, and dual VOR receivers are installed. It appears that, at the present time, very little workload relief can be provided to the single-pilot with regard to other auxiliary tasks such as system selection, ATC interaction, communications, chart reading, check list readings, chart handling, flight clearance writing, etc., unless new and innovative systems and techniques become available.

For a given IFR flight capability and performance level, the artificial stability systems, the Flight Director System and the second pilot all represent sources of flight control workload relief (or modification) for the Pilot-in-Command. However, it should be noted that the workload relief provided by the artificial stability systems and Flight Director (say during a letdown and ILS-CAT I approach), is of a distinctly different type as compared to that obtained by the addition of a qualified, current copilot seated at a fully equipped flight station. In the single-pilot case, the artificial stability systems and the Flight Director System are aiding the pilot in his maneuvering, "attitude-maintenance" task of the helicopter and flight path control or navigation guidance as dictated by his flight plan and objectives. They aid him primarily in his short term flight control of the aircraft. In the two-pilot case, the second pilot probably assumes the major workload associated with the auxiliary tasks of ATC/Communications/Navigation as well as some safety monitoring of the handling pilot and management of helicopter subsystems. As the "non-handling" pilot, the copilot is not directly involved in the flight control of the helicopter. Additionally, there is mitigation of the fatigue factor associated with difficult IFR flight since the pilot and copilot can exchange flight control duties.

The ATC/Communications/Navigation and miscellaneous cockpit management and monitoring tasks which together make up auxiliary workload are all definable, fairly standard, and normally dependent upon the NAS/ATC operational environment. Also, it is generally agreed that the "high-density" terminal areas like the New York City, Chicago and Los Angeles metropolitan areas usually provide the potential for maximum auxiliary workloads. For each flight phase and condition, the effort and attention needed to perform auxiliary tasks is usually a fairly predictable amount. It is a workload level which experienced pilots flying in this environment have learned to appreciate and quantify. When the second pilot is removed from an aircraft, the entire ATC/Communications/Navigation (ATC/COMM/NAV) etc. workload (normally accomplished by the second pilot) is re-allocated to the Pilot-in-Command (PIC). Depending on the personal style or professional attitude on the part of the sole-pilot in the helicopter, this workload associated with the ATC/COMM/NAV etc. task may change somewhat but given the equipment and environment it is, in general, the same quantity task that existed when there were two pilots in the cockpit and the copilot was handling that part of the total workload.

CREW MEMBER RESPONSIBILITIES FOR TWO CRITICAL IFR FLIGHT PHASES

In any discussion of the division of pilot workload, it is helpful to analyze the two-pilot case when dividing total workload into the major types of tasks. It is also beneficial to address it in terms of different, critical IFR flight situations (each with different phases, ATC/COMM/NAV environments) as well as the special conditions of weather and stress, namely:

- IFR, Enroute Flight Phases with high auxiliary task workload.
- IFR, Category I, ILS Approach Flight Phases with high flight control task workload.

In both flight situations:

- The Pilot-in-Command is the handling pilot performing the flight control task and is responsible for flying the aircraft and achieving the maneuvering/steering performance, proper altitude/attitude/speed control and flight path guidance accuracy commensurate with that expected and required for the flight phase.
- The copilot is the non-handling pilot performing the auxiliary tasks and is responsible for all other flight actions including ATC/COMM/NAV duties, subsystem management, cruise control, monitoring the flight activities, and providing support to the PIC for any other miscellaneous activity (chart reading, etc.). He is expected to perform these duties with a rapidity and accuracy commensurate with that required for enroute/cruise type flight where the auxiliary task workload is heavy.

However, when copilot responsibilities in the second (Approach) situation are closely analyzed, additional duties are recognized. The copilot is also supporting the PIC by providing such things as missed approach headings and procedures on go-around. He is also charged with the duty of "looking-out" as the helicopter approaches the critical transition stage from IMC to VMC flight near the Decision Height. This advises the pilot of "ground-contact" or approach light contact so that the PIC can make a smooth transition to VFR for deceleration, flare and landing. If "no-contact" at the Decision Height, the copilot aids him accordingly on the missed approach. The copilot is expected to perform these duties with a rapidity and accuracy commensurate with that required in a high-density, high stress environment during the execution of an ILS, CAT I approach (or missed approach).

Additionally, consideration must be given to the special conditions of weather and environment. These conditions include turbulence, crosswinds on approach, gusts, wind shear, precipitation, night, ceiling, visibility, etc., and are very important to assure critical case appraisal for the IFR certification case. The special conditions of weather considered in this report for the two cases mentioned above are those for a nominally bad IMC day. They might include weather conditions such as moderate turbulence, crosswind from 45 degrees, gusts, wind shear, steady rain, night and Category I type ceilings and visibilities. The conditions are typical of those that the flight examiner has to consider during the IFR certification process.

SECTION 3

PILOT ATTENTION AVAILABLE FOR AIRCRAFT CONTROL

INTRODUCTION

This section analyzes the overall workload associated with a typical IFR flight and identifies separately the auxiliary tasks and flight control tasks. The auxiliary task requirements are quantified through time line analyses for selected flight segments to determine that portion of a pilot's time and attention in which he is drawn out of the flight control loop. The time remaining is concluded available to the pilot for the flight control task.

ANALYSIS OF THE COMPOSITE HELICOPTER IFR FLIGHT PROFILE

In Reference 1 it was found that, when the many different operational roles of civilian helicopters were considered, each helicopter must be prepared to contend with all events contained in a typical IFR flight (e.g. the Composite Helicopter IFR Flight Profile which was developed for Reference 1). That Composite Profile represents a reasonable operational standard for certification of helicopters for IFR flight and is reproduced here (Figures 3-1 through 3-4), excerpted from Reference 1. It includes all probable events of a non-emergency nature. They are based on two sources: (1) the services offered, and/or requirements of, the ATC/IFR environment as it exists today; and (2) contemporary helicopter IFR flight techniques as taught and practiced in the actual helicopter IFR environment.

A narrative was developed to summarize the activities and events for each flight phase of the Composite Helicopter IFR Flight Profile. It states both flight control tasks and auxiliary tasks in a general sense. The narrative summaries are detailed in Appendix B. The Composite Profile presented in this section, and the narrative summaries in Appendix B, are well documented by References 6 through 11.

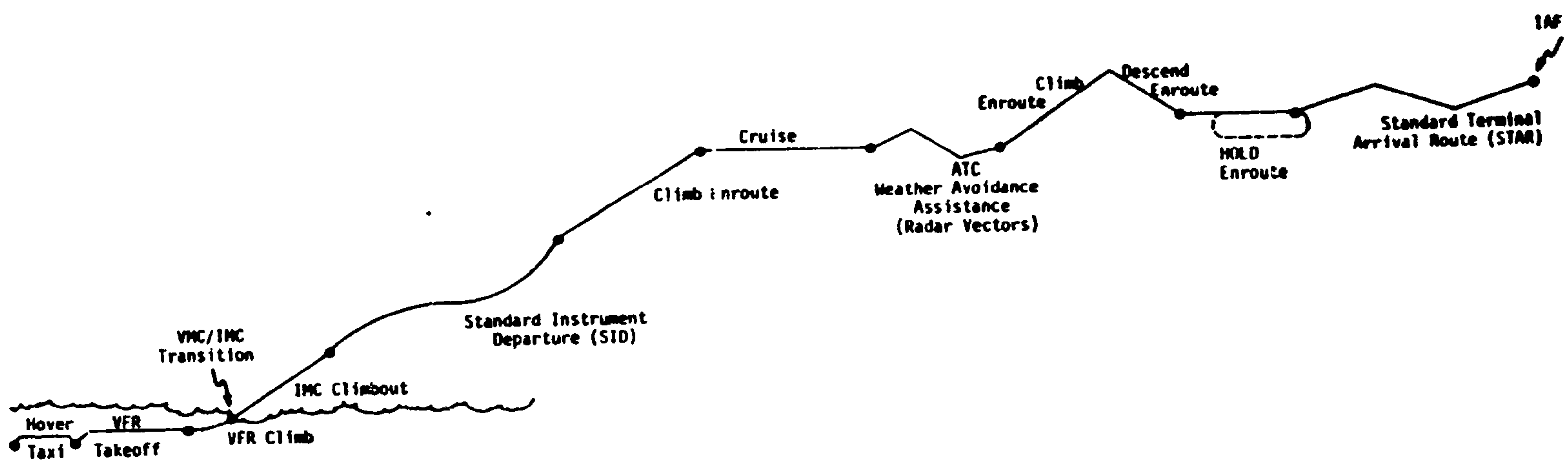


Figure 3-1. COMPOSITE HELICOPTER IFR FLIGHT PROFILE
(Departure and Enroute)

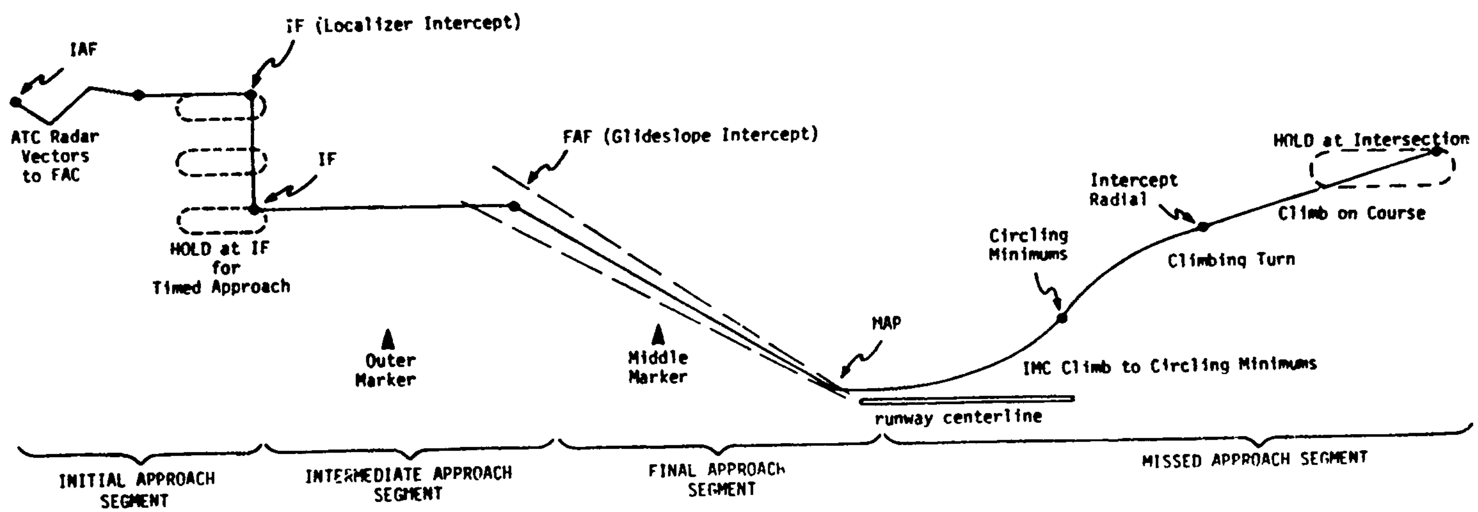


Figure 3-2. COMPOSITE HELICOPTER IFR FLIGHT PROFILE (Approach and Missed Approach)

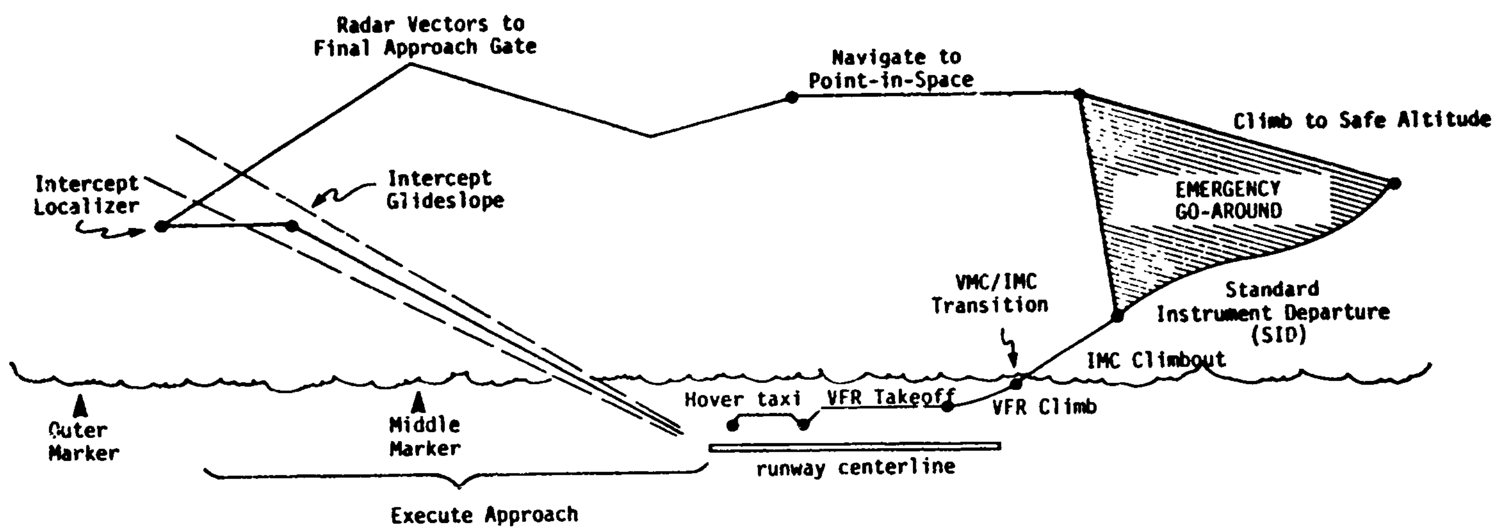


Figure 3-3. COMPOSITE HELICOPTER IFR FLIGHT PROFILE
(Emergency Go-Around/Precautionary Return-to-Landing)

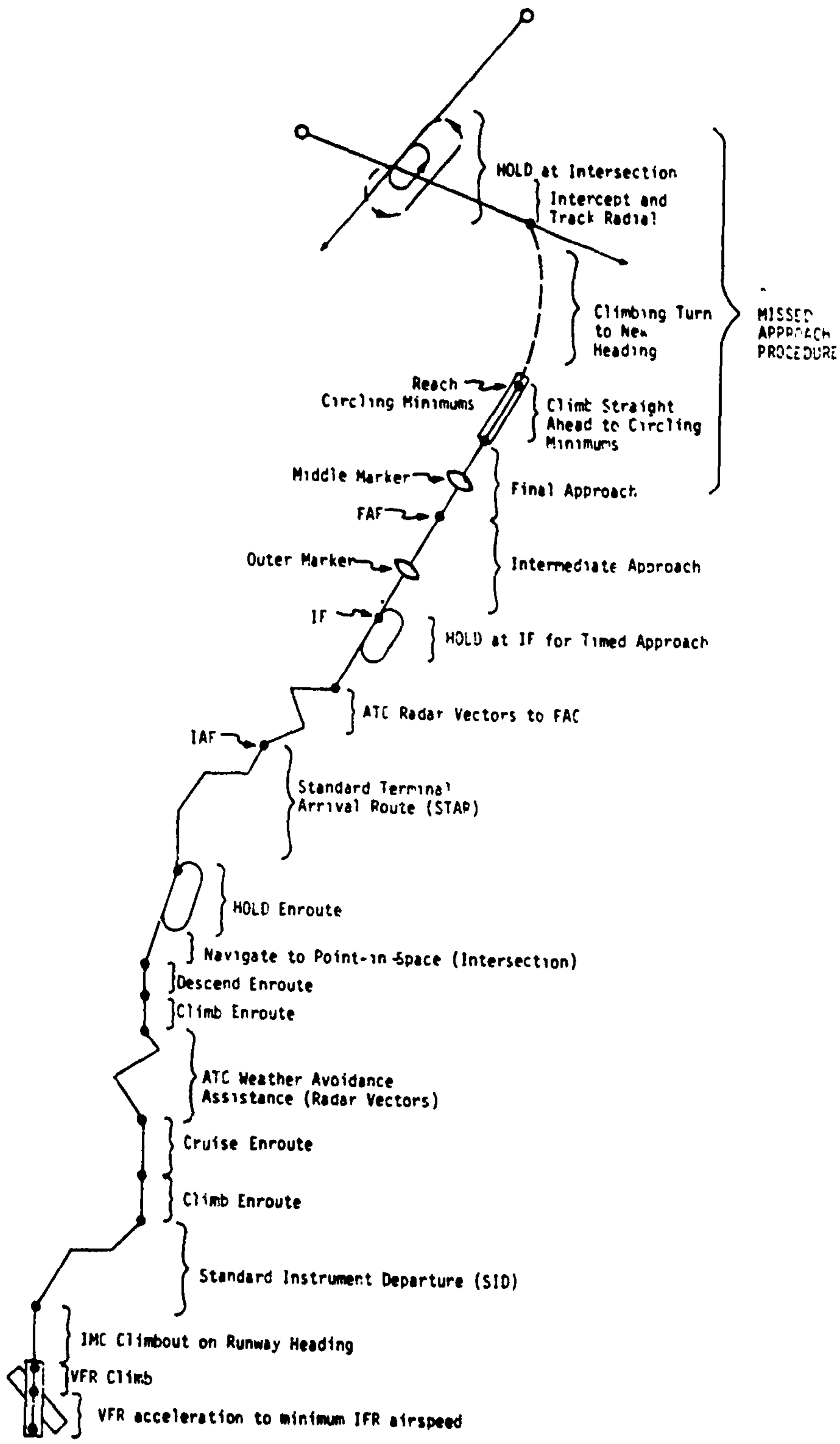


Figure 3-4. COMPOSITE HELICOPTER IFR FLIGHT PROFILE (PLAN VIEW)

ESTIMATING AUXILIARY TASK WORKLOAD REQUIREMENTS

As discussed in Section 2 of this report, the auxiliary tasks which a pilot is required to perform are, in general, fairly predictable, definable and dependent upon the operational environment. Conversely, that portion of a pilot's attention required to control an aircraft may vary widely dependent upon such factors as: aircrew experience, skill level, mental and physical well-being, environment, and the flying qualities of the aircraft. Determination of the auxiliary task workload requirements will, however, yield that remaining portion of a pilot's attention available for aircraft control. Before attempting the quantification, two questions must first be addressed:

- During which maneuvers will a pilot allow/permit, or prefer to accomplish, auxiliary tasks if given a choice?

- During which maneuvers are externally generated, auxiliary tasks most likely to be forced upon a pilot?

These questions should be answered in light of the two types of pilot tasks used in the definition of pilot workload -- flight control tasks and auxiliary tasks. In order to arrive at preliminary answers to these questions, a number of pilot interviews were conducted and instrument instruction schools were queried. In respect to the first question, it was almost invariably felt that a single pilot, given a choice, will elect to defer auxiliary tasks until the more ideal flight conditions are achieved -- i.e., when straight and level rather than turning, climbing, or descending or transitioning from one of these phases. Moreover, in a steady state climb or descent not exceeding an approximate rate of 500 fpm, a pilot could and would accept an auxiliary task of a relatively short duration.

The second question, however, recognizes that the choice is not always left to the pilot and some auxiliary tasks may be forced upon him at undesirable times. Examples of the latter are of two kinds -- unanticipated and anticipated. Unancitipated task loading, such as change of clearance in the early portions of a Standard Instrument Departure, are an inescapable and recurring situation. Worse, is the unwelcomed, yet anticipated, auxiliary task loading associated with holding (knowing that further clearances are to come while executing the holding pattern) and the missed approach.

It should be further recognized that in addition to the expected auxiliary task workloads associated with departure, holding and missed approach; the enroute portions of IFR flights can be equally demanding, or even higher, in terms of auxiliary workload, especially when flying in high-density traffic areas.

An underlying truism which should temper any analysis of pilot workload is that there are flight conditions under which an unusual attitude can develop if a pilot makes the mistake of accepting an auxiliary task when the flight control task will not permit it. Additionally, although pilots may prefer reduced auxiliary task-loading during the more demanding maneuvers, there is little they can do about it when under IMC conditions and under the direction of ATC facilities.

One important cockpit management factor must be taken into consideration, however. No matter what requirements may be placed on the pilot by ATC, he has one undisputable capability: the distribution or segmentation of auxiliary tasks to compensate for the need to attend to flight control tasks. In other words, the pilot is not expected to drop everything to respond to ATC requests immediately. He may elect to accomplish unexpected auxiliary task requirements in segments rather than totally neglecting, or subordinating, flight control tasks or, with respect to distribution, he may defer the entire task or segments of the task (depending on the circumstances) for a few moments to avoid total or excessive subordination of the flight control task.

METHODOLOGY TO DETERMINE AUXILIARY TASK WORKLOAD LEVELS

The methodology and its selection described below was accomplished independent of, and is in agreement with, Reference 12. As discussed in Section 2, the total workload of the aircrew can be divided into two parts; namely, the workload associated with the flight control task and workload associated with auxiliary tasks. Auxiliary tasks can be classed as either overt (e.g., copying a clearance, performing checklist items, etc.) or covert (e.g., mental processes, decision making, etc.). Of the two types of auxiliary tasks, the overt ones are more easily observable and lend themselves more readily to quantification and estimation of workload required.

Certain of those overt auxiliary tasks can be easily predetermined for all the flight segments of the Composite Profile and their respective phases and subphases. These generally are ATC-related tasks and they represent a substantial amount of the total auxiliary task-loading that exists; thus, allowing the analyst to approximate that portion of a pilot's attention available for flight control tasks. Four specific situations were identified, by reviewing the Composite Profile narrative, as being critical flight segments (e.g., those having the highest potential auxiliary task-loading): Departure, Enroute, Holding, and Missed Approach. Auxiliary tasks during the final approach segment (Figure 3-2) are, for the most part, subordinated by the pilot to maximize attention to the flight control task. Also, the ATC system, by design, tends to minimize its contacts and requests during this segment. Therefore, the final approach segment was not considered as a candidate for examination.

The methodology chosen was to conduct time line analyses of those selected auxiliary tasks for each of the critical flight segments. The tasks selected for analysis were the easily observable tasks which are readily quantifiable and ideal for time line analysis procedures. This accounted for the vast majority of auxiliary tasks.

All tasks for the four flight segments of interest were itemized (The complete itemizations are presented for reference in Appendix C). The overt auxiliary tasks were listed in detail sufficient enough to facilitate later assignment of the time requirements to complete each task. The flight control tasks were listed only in a general manner because they would not require substantial quantification during the analyses, but were necessary to provide continuity to the sequence of events in each flight segment.

TIME LINE ANALYSIS OF CRITICAL FLIGHT SEGMENTS

Time line analyses operate on the principle that workload can be operationally defined by the ratio of the time during which an operator is performing some task-related activity to the total time available. When this ratio is one, so that the operator is constantly occupied by some aspect of the task, then his workload is considered to be 100%. This method is valuable as a rough approximation of workload. It does, however, have two limitations: First, it makes no distinction between the levels of demand and time-sharing; and, second, it is normally restricted to recording "overt" activities (Reference 13).

The first limitation is accounted for in part by recording only those auxiliary task activities which required an obviously substantial level of attention. Substantial means that the task would draw the pilot out of the flight control loop to such an extent that there was no doubt that the flight control tasks would have to be subordinated. The second is one that is addressed by the academic community with nearly as many approaches and solutions as there are participants in workload assessment projects. There was no misgiving about the use of only overt activities, since the purpose of the analyses in this section is to allow the approximate determination of that portion of the pilot's attention available for aircraft control.

Three major factors directly impact the auxiliary task workload during helicopter IFR flight. Any attempt at their quantification in the workload assessment process would tend to become a subjective task. Their effects on auxiliary task workload are addressed below:

- the capability to distribute or segment auxiliary tasks varies from one pilot to the next and is used differently;
- the area being navigated determines the types and quantity (thus, frequency) of ATC-related auxiliary tasks (e.g., TCA versus cross-country in low-density traffic area);
- for a given flight, a change in airspeed will change the amount of time available to complete the required tasks, thus changing the denominator of the time line analysis ratio.

The three factors cited above were addressed in the time line analyses, by making the following basic assumptions:

- distribution capability was not significantly allowed, in order to reflect closer to the average minimum helicopter pilot than the highly experienced, well-disciplined pilot. Limited segmentation capability was applied by allowing pauses of 10-15 seconds between short, sequential, auxiliary tasks. In the case of the more lengthy tasks (reviewing approach charts and calculating flight information), it was assumed that pilots would inherently not desire to be out of the flight control loop for periods longer than probably about 30 seconds. Such momentary, in-the-loop periods were not interspersed during those tasks because they vary from one pilot to the next, and also would not affect the numerator of the time line analysis ratio significantly;

- a high-density traffic area was used since that is the ultimate operational environment within which an aircraft is certified to operate, except for SFAR and special waiver situations;

- effects of airspeed (distance travelled for a given period of time) were not directly considered in an effort to develop a set of conditions as constant as possible for the analyses.

Two other basic assumptions were made to establish conditions for the time-line analysis:

- the analysis was conducted based on single pilot operation. This frames the workload assessment, in the most basic terms, which is applied in later sections of this report. It must be remembered that the analyses are concerned primarily with determining the total approximate overt auxliary task workload, not the effects of various aircrew manning levels;

- Equipment configuration was established at a relatively unsophisticated level. Cockpit configuration included a single VHF NAV receiver, dual COMM receivers, and only minimum required instruments and equipment for IFR flight. Aircraft configuration was established as a single-engine, single-rotor, helicopter with no augmentation subsystems requiring cockpit management and no autopilot-type functions (i.e., attitude retention, automatic navigation modes). No flight director system was included.

It must also be remembered that, for this study, the purpose of these time line analyses is not to record the varied minutiae and <u>levels</u> of attention associated with the non-flight control activities of each critical segment. Rather, their purpose is to demonstrate the extent of possible periods of auxiliary task workload and to estimate those periods in which a pilot is drawn almost totally out of the flight control loop.

A sample time line analysis format is provided in Figure 3-5. Results of the time line analyses for each of the four critical flight segments are presented graphically in Figures 3-6 through 3-9. The four are shown together for comparison in Figure 3-10. A brief summary of the flight segment accompanies each time line analysis. An itemized list of specific tasks analyzed for each segment appears in Appendix C.

Refer to Figure 3-5 for a guide to interpretation of the graphs. Time is shown in minutes along the horizontal axis. The time required to complete the selected auxiliary tasks is recorded to the tenth of a minute using vertical blocks along the time axis. The height of the blocks is unimportant. Each block represents a single auxiliary task. For example, the first block (0.4 minutes in duration) could be the time it takes to receive and copy a lengthy clearance from ATC. The second block (0.3 minutes) could be the time it takes to read back that clearance.

Various periods of activity are isolated by marking their durations below the time axis. The workload for activities recorded (in this case, ATC-related auxiliary tasks which definitely take the pilot out of the flight control loop) is given as a percent for each period. The percentages are derived by dividing, the sum of the time expended on activities within a period, by the total time (duration) of the period. For example: 90% for Period 3, Figure 3-5, was derived by dividing 1.8 (1.4 + 0.4) by 2.0 (duration). Appendix C contains a sample procedure for the Departure Segment, reproduced in its entirety. The periods are selected arbitrarily for the flight segments of interest in an effort to identify those peak periods of activity for the tasks selected.

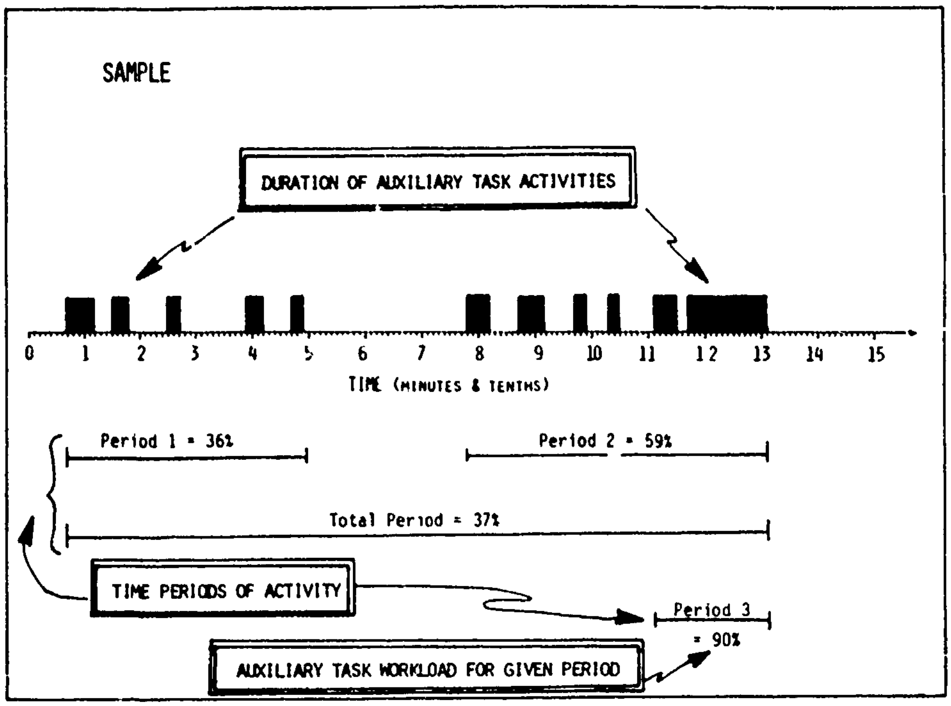


Figure 3-5. Sample Time Line Analysis Format.

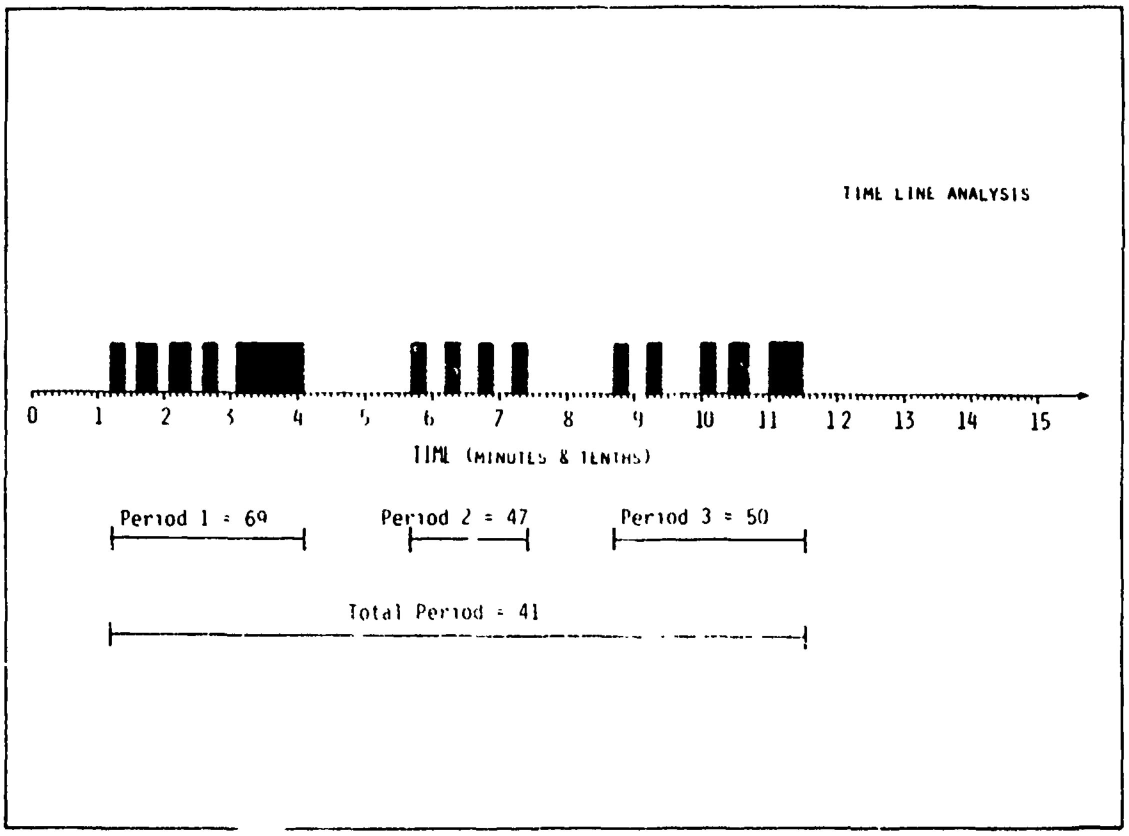


Figure 3-6. Time Line Analysis, Departure Segment.

The Departure Segment includes the IMC Climbout and Standard Instrument Departure, and possibly initial portions of the Climb Enroute flight phase. In this situation the pilot first maintains a relatively high power setting for a desired rate of climb, then commences to execute either a SID or similar ATC clearance. While executing a departure clearance, pilots occasionally receive amendments and must comply with course changes. The significance in changing or amending the pilot's initial clearance is not only in the navigation portion of auxiliary tasks, but also in the additional communications workload imposed on the pilot. A detailed list of tasks is presented in Appendix C.

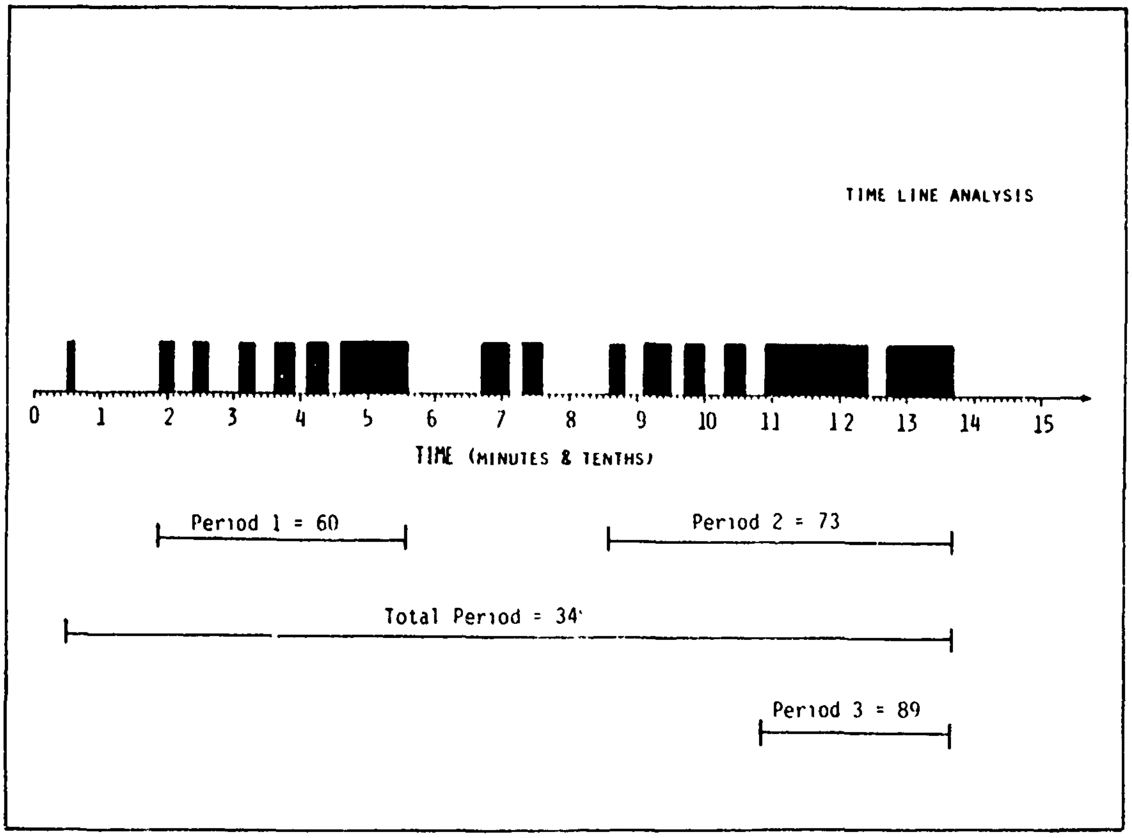


Figure 3-7. Time Line Analysis, Enroute Segment.

The Enroute Segment includes those portions of the flight after the helicopter has reached the initially assigned cruising altitude, with departure procedure complete. It encompasses straight and level flight as well as climbs and descents enroute. The enroute portion of IFR flights can be quite cumbersome when traveling through high-density traffic areas such as Terminal Control Areas (TCAs) and the Northeast Corridor. A detailed list of tasks is presented in Appendix C.

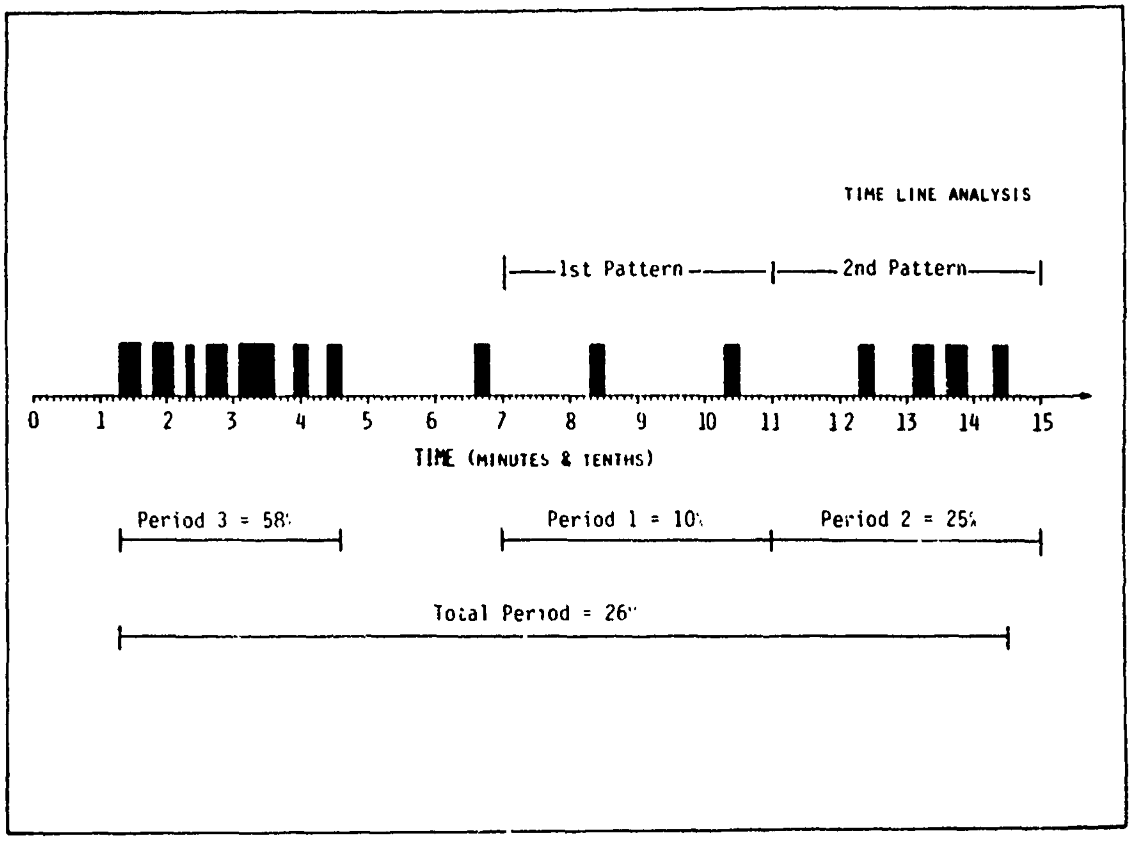


Figure 3-8. Time Line Analysis, Holding Segment.

The <u>Holding</u> Segment can be either of the published or unpublished type. Typically, a published holding pattern will be reasonably simple no matter which direction the turns are. The more complex holding patterns involve those which are unpublished. An example of this would by when ATC directs an IFR helicopter to hold at a prescribed intersection on an unpublished radial which requires an entry other than direct. This is the situation addressed here, beginning at the cruise flight condition prior to receiving holding instructions from ATC. A detailed list of tasks appears in Appendix C.

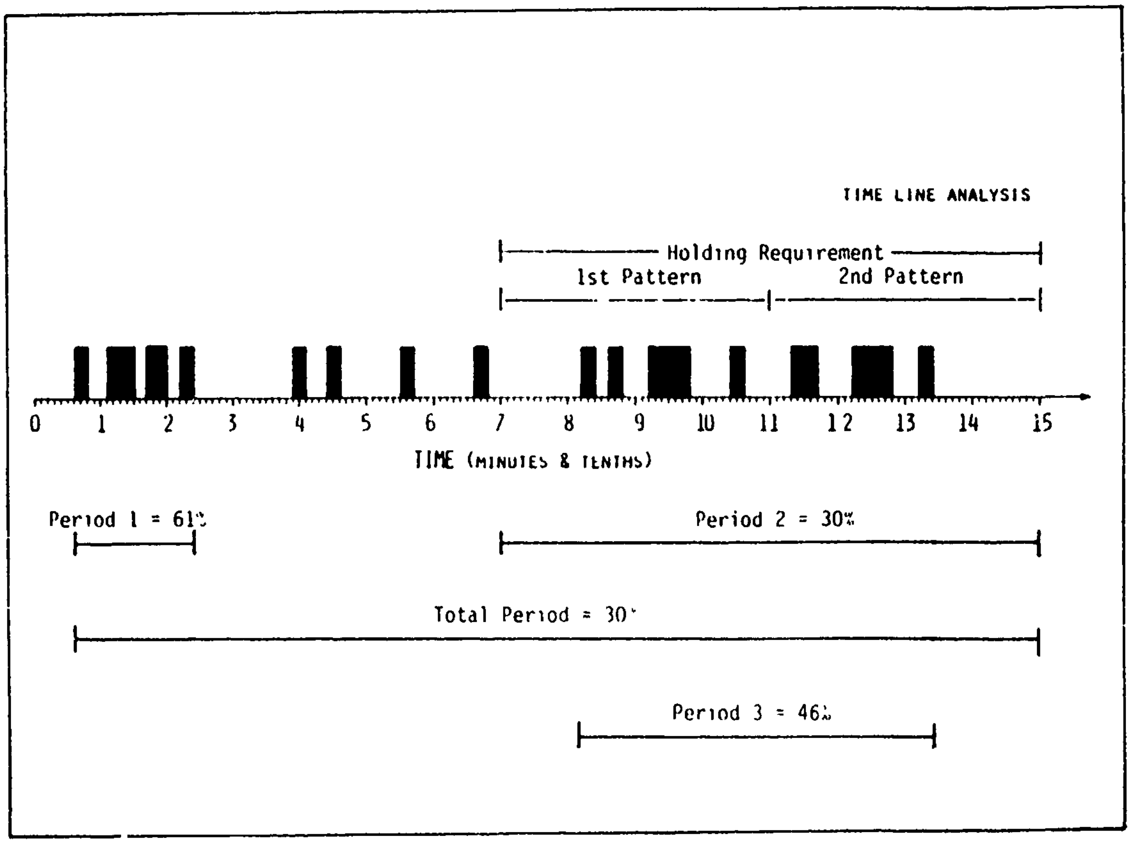


Figure 3-9. Time Line Analysis, Missed Approach Segment.

The Missed Approach Segment is usually a high-stress situation. A more complex missed approach would typically consist or: changing from a rate of descent established on a final approach to a high power climb on runway heading, climbing turn to a new heading (still with a considerable climb rate), intercept a VOR radial and climb to an intersection for holding, possibly with level off during the holding pattern. Throughout this flight segment, there are considerable auxiliary tasks incurred which cannot be put off easily. A detailed list of tasks is presented in Appendix C.

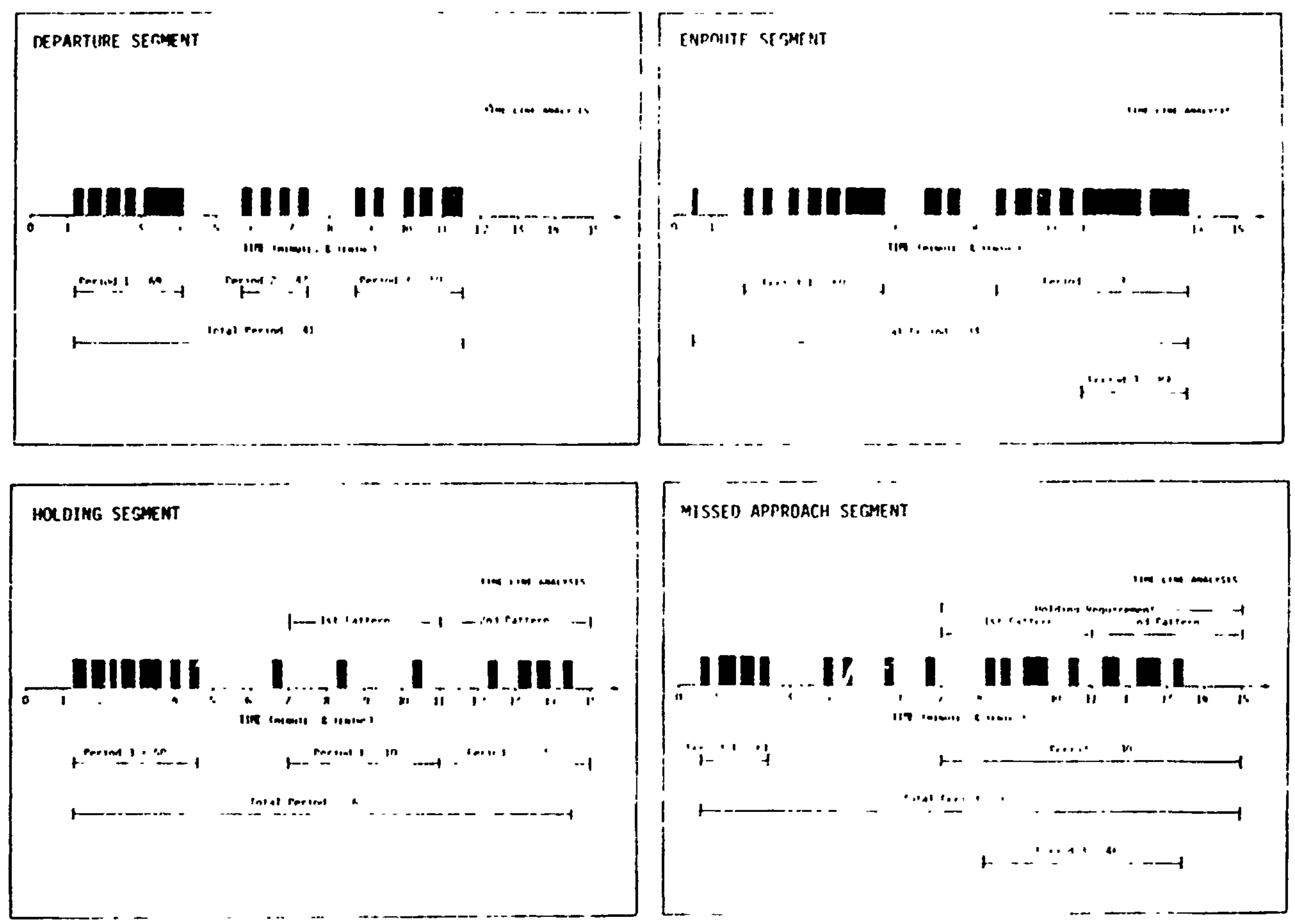


Figure 3-10. Comparison of Results of Time Line Analyses.

FINDINGS OF TIME LINE ANALYSES

The results of time line analyses for the four flight segments of interest are shown together for comparison in Figure 3-10. These reflect the auxiliary task workload for each segment, and selected periods of concentrated activity. Appendix C details the complete list of those tasks addressed in each flight segment.

When comparing the results, it was found that a relatively high auxiliary task workload (greater than 50%) existed in all four of the flight segments for one or more of the example periods. The durations of the high workload periods ranged from just under two minutes to a full five minutes. The shortest was Missed Approach Period 1 (61% for a period of 1.8 minutes) and represented the initial climbout of the departure segment wherein the pilot received an amended clearance and was drawn out of the flight control loop to copy and readback a clearance, then recalculate portions of his flight plan. The longest period of high auxiliary task workload was Enroute Period 2 (73% for a period of 5.1 minutes) and represented a portion of the enroute segment wherein the pilot changes to the next ATC facility, makes a required position report, and then reviews approach charts in preparation for an imminent arrival at destination. Within the longer period, Enroute Period 3 is shown at 89% for 2.8 minutes to exemplify the consequences of accepting certain auxiliary tasks without any segmentation of tasks. The first block in Period 3 represents reviewing approach and missed approach procedures for destination; while the second is the locating and preliminary review of the alternate approach chart.

The significance of the time line analysis results is that approximations are established that confirm that there are definite requirements for auxiliary tasks that would:

- draw a single pilot out of the flight control loop for periods ranging from 10-15 seconds to as much as one-and-a-half minutes (without segmenting tasks); and that

- concentrated periods of auxiliary task requirements exist that can last for as much as two to five minutes.

The significance was stated above in the most basic terms. But the importance of those findings is farther reaching, with implications that directly relate to the dynamics of a helicopter in the stability and control sense. They are especially important when it is anticipated that the combined man-machine performance will be expected to maintain a level of achievement (i.e., performance objectives, which will be developed in Section 4). These and related implications are summarized in a general sense below:

- each helicopter will typically depart from an established flight path if left unattended, or if uncorrected, to an extent dependent on its own, inherent flying qualities.

- knowing that pilots will be drawn out of the flight control loop to satisfy certain auxiliary task requirements, it is then expected that an adequate level of flying qualities must be inherent, or provided, for those periods of concentrated auxiliary tasks.

- when concentrated periods of auxiliary tasks are required, the man-machine combination must still be able to maintain a level of performance - thus, requiring an adequate level of flying qualities.

- adequate flying qualities can be provided in several ways: through design, to be inherent; or through artificial means that range from relatively simple, mechanical stability augmentation to sophisticated, autopilot systems.

- lacking the means, or desire, to provide the appropriate flying qualities commensurate with the "pilot-out-of-the-flight-control-loop" periods identified earlier: the auxiliary tasks required of the single-pilot (which draws him out of the loop) must be reduced - this can be done by means such as improved avionics which facilitate the ATC/COMM/NAV tasks (like DME ground speed and/or ETA readouts, pre-programmed radio frequencies, etc.); or, there must be a sufficient crew manning level to accomplish all required tasks.

- the consequences of short periods (10-15 seconds) and long periods (as much as one minute) of auxiliary tasks are different in that departure from desired flight paths can be significantly greater in the latter.

- if only short periods of auxiliary tasks were encountered, there could be a minimum of stability augmentation necessary.

- if long periods of auxiliary tasks are to be anticipated, then some means of flight path maintenance could be expected - such as sufficient augmentation, autopilot or a second pilot.

- it appears that the <u>auxiliary task workloads</u> (which require a pilot to be out of the flight control loop) are such that they could be handled in their entirety by one person alone with a reasonable reserve remaining, given that they were the only tasks required of that person.

SECTION 4

PERFORMANCE OBJECTIVES

INTRODUCTION

This section addresses a central question to the development of any workload evaluation process. Given available flight control workload established, what are the performance limits? Two levels of routine performance are addressed (normal and adequate) plus one level of non-routine/emergency (transient) performance. Guidelines are established for adequate performance objectives.

The interdependence of workload and performance is described as it applies to flight control tasks and the amount of time and effort available for them.

GENERAL

A central issue in the determination of satisfactory handling qualities for IFR certification of helicopters is the requirement that the pilot/aircraft system be capable of achieving a specified level of performance with an acceptable level of air crew workload for a given set of conditions, configuration, and task. For this discussion it is beneficial, from the standpoint of standardizing the terminology on this subject, to note two fundamental definitions as related in Appendix A and excerpted from Reference 3. These are the well known Cooper-Harper definitions of Performance and Compensation. They are defined as:

- PERFORMANCE - The precision of control with respect to aircraft movement that a pilot is able to achieve in performing a task. (Pilot-vehicle performance is a measure of handling performance. Pilot performance is a measure of the manner or efficiency with which a pilot moves the principal controls in performing a task).

- COMPENSATION - The measure of additional pilot effort and attention required to maintain a given level of performance in the face of deficient vehicle characteristics.

The term "COMPENSATION" is needed for discussions here and in later sections of the report. It indicates that a pilot must increase his workload to improve aircraft performance for a given aircraft and task and is related to the difficulty a pilot has in completing a task with the precision required for that specific task. The total workload is the sum of the workload due to compensation (for the handling qualities deficiencies of the helicopter) and the workload due to the task (Reference 3).

Pilot workload descriptors for different levels of compensation needed for different levels of handling qualities for a flight control task may be generated. The following descriptors were developed here to be representative of the compensation levels as required for flight control and are applicable to helicopter IFR operations:

- Minimal pilot compensation. Control techniques are relaxed. Continual pilot involvement in short and long term flight control task.

- Moderate pilot compensation. Pilot is moderately involved in the flight control task, but must continually correct the short term state of the aircraft.

- Considerable pilot compensation. Pilot is heavily involved in the flight control task. The pilot would not intentionally plan to encounter this level of effort for more than 5-10 minutes.

- Extensive pilot compensation. Pilot is very heavily involved in the flight control task. The pilot would not intentionally plan to encounter this level of effort.

- Maximum pilot compensation. Pilot is totally involved in the control task. The pilot would not intentionally plan to encounter this level of effort.

The last two descriptors differ in that the level of pilot compensation changes from extensive to maximum. The significance of this difference is that, although in both cases the pilot would not intentionally plan to encounter the level of effort, the last descriptor was added to define the limit of pilot workload. This was done to assist in the assessment of failure-mode operation of an aircraft and is discussed later in Section 7.

DETERMINATION OF PERFORMANCE OBJECTIVES

An important issue in determining acceptable flying qualities for IFR certification of helicopters should obviously be to establish those performance objectives which an instrument pilot should be expected to achieve when utilizing his aircraft system. A review of numerous publications was made to determine performance objectives that were directly applicable to IFR operations. The most pertinent available document that specifies operational performance objectives in quantitative terms was Advisory Cirular AC-61-64, Flight Test Guide: Instrument Pilot-Helicopter (Reference 14). The performance objectives as stated therein for altitude, airspeed and heading were used as a basis for developing those to be used in this study because they represented the demonstration criteria (minimum performance levels) for helicopter instrument pilots. Applicable criteria were extracted and used as a basis to quantitatively present limits of performance for flight maneuvers to be developed later in this report. Adequate Performance Guidelines (Table 4-1) reflect the minimum performance levels extracted directly from Reference 14. These guidelines were recognized as applying to the minimum level of achievement for a "nominal-bad" IMC day. A better than adequate performance level is both desired and expected for less than that "nominal-bad" IMC day.

In addressing those objectives, consideration must be given to factors such as the readability and responsiveness of cockpit instruments as well as the anticipated capabilities and skill levels of the pilot for which the aircraft is being certified. Only adequate performmance guidelines are offered for reference, since it is felt that only adequate objectives are proper to ask for and identify in defining a level of safety for IFR operations. The better than adequate performance could be described as normal/desired and is an improved level sought by manufacturers and owners/operators. It is generally determined between themselves in the form of (or by selection of) avionics or system options, equipment specifications, and the levels of pilot qualifications and proficiency.

TABLE 4-1

ADEQUATE PERFORMANCE GUIDELINES

	Altitude (Ft)	Airspeed (Kts)	Heading (deg)
Straight and Level Flight:	±100	±10	±10
Turns: level, climbing, descending; standard rate, timed turns to heading; steep turns.	±100	±10	±10
Climbs and Descents: Constant speed; Constant rate; to altitude	±200 ft/min	±10	±10
VOR Approach: (descend at the proper rate to MDA)	e < 100 ft below alt no descent below MDA	±10	NA
ILS Approach:	no descent below DH e < 100 ft below during initial app e < full deflection of GSI	±10	e < full deflection of CDI
LOCALIZER Approach: (descend at proper rate to MDA)	e < 100 ft below during initial app no descent below MDA	±10	e < full deflection of CDI
ADF Approach:	"	±10	NA
Engine - Out: Single engine	NA	±10 kt of recommended	±20
Twin engine	±100 ft	±10 kt	±20

LEGEND: e = error
</> = less/greater than
NA = not applicable

PERFORMANCE AND WORKLOAD INTERDEPENDENCE

During the conduct of a flight operation or flight phase, any judgment of the handling qualities of a given pilot/vehicle system, for a given task, quickly reveals the strong functional relationship between performance and workload. The study areas of performance (precision of aircraft control) and workload (pilot effort and attention) are extremely interdependent handling qualities factors and obviously are subject to tradeoff by the pilot. In general, it is always presumed that precision of aircraft control cannot be defined or related independently of the amount of effort and attention provided by the pilot in the conduct of any task (Reference 3). Therefore, whenever a level of workload is discussed, a level of performance is implied. Three categories of precision of aircraft flight control (normal, adequate, and transient) are discussed in this section. The tradeoff between these performance levels and levels of pilot workload is readily understood.

As an example, two cases are discussed. First, for a specific helicopter and a given level of handling qualities factors (such as stability and control characteristics, displays, etc.), the pilot may achieve <u>normal</u> flight path control performance with flight control workload levels which do not exceed <u>moderate</u> pilot compensation. He is not totally involved in the flght control task but must continually correct the short term state of the aircraft. The pilot may, at times, approach a marginal normal workload level. In the second case, for a different helicoper that has poorer handling qualities characteristics (as compared to the vehicle in the first example above), the pilot may achieve only <u>adequate</u> flight path control performance with flight control workload levels which do not exceed <u>moderate</u> pilot compensation. If he desires to achieve the higher precision of aircraft control defined as <u>normal</u> flight path control performance, he will have to increase his flight control workload level. He can compensate for certain deficiencies of this helicopter and it is tolerable to him, but if he is asked to continually provide greater precision of aircraft control, he will probably require that the handling qualities of this aircraft be improved.

The following general definitions are provided for Normal (Desired) and Adequate performance:

<u>Normal/Desired Performance</u> -- that performance which a pilot is expected to achieve during day or night IMC operations in a lightly turbulent or better environment. It is that performance limit which is readily observed by a motivated pilot qualified in type, and current in model.

Adequate Performance -- that performance limit which may be approached during IMC operations in a moderately turbulent environment. It is that performance limit which can clearly be observed by a pilot qualified in type and current in model, with no motivation other than that provided by the normal desire of a pilot to maintain safe flight operations.

A third level of performance that is identified is -- Transient Performance. This third level of performance, however, mainly addresses the dynamics of failure and short-term external disturbances which do not lend themselves to a quantitative presentation of guide-lines. It tends to vary (pilot capability aside) with each individual aircraft model. Guidelines for this performance level were not formalized. They must be determined relative to unusual flight conditions, which in themselves define transient performance. The relationship of unusual attitudes and flight conditions is addressed in the following pages. A general definition is given below.

TRANSIENT Performance -- that performance limit which may be approached during IMC operations, as a result of unusual turbulence, engine failure, stability/control equipment failure, or a crew blunder error. The pilot must not be misled by the resulting condition once alerted to the existence of the departure. Once alerted, the pilot must be able to quickly and safely return to normal operations without the tendency to misuse the controls. That is, conventional control techniques shall not precipitate a secondary excursion beyond one or more performance limit(s). To proceed beyond this limit would place the aircraft in imminent danger.

UNUSUAL FLIGHT CONDITIONS

Any discussion of workload levels associated with helicopter instrument flying would be incomplete without addressing the subject of unusual attitudes and unusual flight conditions that could conceivably occur.

The FAA Instrument Flying Handbook, Advisory Circular 61-27B (Reference 8) states that:

> "An unusual attitude is any aircraft attitude not normally required for instrument flight. Unusual attitudes may result from a number of conditions, such as turbulence, disorientation, instrument failure, confusion, preoccupation with cockpit duties, carelessness in cross-checking, errors in instrument interpretation, or lack of proficiency in aircraft control. Since unusual attitudes are not intentional maneuvers during instrument flight, except in training, they are often unexpected, and the reaction of an inexperienced or inadequately trained pilot to an unexpected abnormal flight attitude is usually instinctive rather than intelligent and deliberate."

There is a greater potential for unusual attitudes and flight conditions in helicopters over airplanes because helicopters have a more complex relationship between power, torque, trim stability, cross-coupling effects, etc.

Helicopter unusual attitudes, other than equipment failures and vertigo-induced or turbulence-related, result almost exclusively (under IMC) from high auxiliary task workloads when a pilot's attention is drawn to non-flight control tasks to such an extent that he allows the aircraft to deviate from the intended flight path or attitude. Similarly, un-noted equipment failures can result in an unobserved error buildup during high auxiliary workload situations. Also, note that turbulence can mask the force cues which normally combine with visual cues to alert the pilot to error buildup.

In Section 3, certain flight segments were identified in which potentially high, auxiliary task workloads existed. Those flight segments are highlighted again below (a more complete summary of each appears in Section 3):

- Departure -- involving clearance changes and initial flight navigation immediately following VMC/IMC transition during an IMC climbout.

- <u>Holding Patterns</u> -- involving pilot management of holding pattern while recomputing or rechecking ETAs or flight plan on the basis of delays caused by holding, or anticipation of ammended clearance.

- <u>Enroute</u> (Cruise, Climb and Descent) -- involving workload normally associated with high-density traffic areas, the extensive communications requirements in non-radar environments, and circumstances such as receiving an ammended clearance or the auxiliary task workload necessary to comply with SID or STAR requirements.

- <u>Missed Approach</u> -- in which both the decision-making and communication workload is at a high point, while executing a high power, high vertical rate, climbing turn.

Of importance here is that, with respect to the performance/ workload relationships in helicopter IFR operations, the potential for entry into unusual attitudes and flight conditions exists typically when high auxiliary task workload draws the pilot from his flight control tasks. Although it is simplistic, it should be noted that, once an unusual attitude is evident, a pilot will subordinate all but those tasks necessary to regain satisfactory control of the aircraft.

The workload relative to the possibility of unusual attitudes and flight conditions must be viewed from two perspectives: first, recovery in the event that they develop; and, second, prevention of their occurrence. The peaking workload levels typically associated with <u>recovery</u> from unusual attitudes can be characterized as infrequent, random and of short duration.

On the other hand, the workload associated with <u>preventing</u> the occurrence of unusual attitudes can be characterized as continual and everpresent. Also, that workload level will vary depending on the handling qualities of the helicopter in question and the many factors which affect those handling qualities. In effect, that workload required to meet stated performance objectives for the particular flight task will tend in itself to prevent unusual attitudes of other than the turbulence-related or vertigo-induced kind.

SECTION 5

WORKLOAD/PERFORMANCE IMPLICATIONS FOR SINGLE AND DUAL PILOT OPERATIONS

INTRODUCTION

This section extends the understanding of the role of pilot workload in the IFR certification process through a discussion of the workload/performance implications for single and dual pilot operations.

The flight situations (cases) are examined (reflecting the two different types of workload): Enroute, which predominantly has a high auxiliary task workload; and Approach, which predominantly has a high flight control task workload. Each of the two cases is discussed with respect to both single and dual pilot operations to clarify the variations in workload requirements necessary for each to achieve stated performance objectives developed in Section 4. Case discussions are graphically depicted utilizing the pie-chart scheme devloped in Section 2.

GENERAL

In conformance with the framework and terminology used to depict and relate aircrew workload factors and manning levels in Section 2 of this report under the sub-title "DISCUSSION OF AIRCREW WORKLOAD FACTORS," the following discussion is offered. In Section 2, Figure 2-2, a pie-chart system is utilized to depict the total available workload capabilities for two-pilot (pilot and copilot) aircrew manning levels. In Figure (b) of 2-2 the cross-hatched area represents that part of the pilot's total workload capability earmarked for "RESERVE" workload capability. As defined in Section 2, RESERVE is that portion of the (100%) total workload capability that an aircrew member chooses to keep open or not allocated during routine/non-emergency flight situations.

Two critical IFR flight phase cases (outlined in Section 2) are of interest. They are:

- IFR, Enroute Flight Phases with high auxiliary task workload (Case I).

- IFR, Category I, ILS Approach Flight Phases with high flight control task workload (Case II).

Case I represents the Enroute situation where the flight control workload is moderate and commensurate with the enroute flight phases. However, with respect to auxiliary tasks, the case chosen here represents the moderate to high workload levels associated with heavy auxiliary task duties. On the other hand, Case II represents the precision flight control case for CAT I, ILS approaches. The flight control workload level is high and the auxiliary workload level is lighter and more typical for that associated with the later stages of intermediate segment of the approach (Figure 3-2) and "close-in" flight on final.

The special conditions of weather and environment are as previously mentioned in Section 2 and include moderate turbulence, crosswind from 45 degrees, gusts, wind shear, steady rain, night, and Category I type ceilings and visibilities.

In the following Sections (using the framework and terminology depicted in Figure 2-2), additional pie-charts are constructed for both critical IFR flight phase cases for both one and two-pilot aircrew manning levels.

ENROUTE FLIGHT PHASES (CASE I)

If the workload piechart is constructed to display the division of flight control workload versus the auxiliary task workload for the two-pilot, enroute IFR flight phases, it could appear as shown in Figure 5-1. For these discussions, it is important at the outset to understand that the exact or absolute values of the percentages are not as critically important as the relative changes and total levels of workload. In each case the piecharts are intended to depict, in a general but authentic way, actual cases of pilot/vehicle versus workload level as manifested by some of the recent IFR certifications of helicopters. During the survey trips and data/information searches, certain material and commentaries revealed specific requirements and criteria on allowable flight control and auxiliary task workload levels and current methods for workload relief. The piecharts attempt to reflect general methodologies and parameters involved in these actual cases as accurately as possible and the percentages are used in the graphs not to reflect actual, measured workload data but rather in the sense that they may make the arguments for the different examples easier to follow.

Two-Pilot Operation

In Figure 5-1, the piechart shows that the Pilot-in-Command (the handling pilot) is flying a helicopter whose overall handling qualities are such that he utilizes about half (50%) of his total available workload capability for the flight control task for this aircraft in the IFR Enroute flight phases. During some portions of the enroute flight the workload may be lighter if everything is going well whereas in other portions it may be heavier due to increased turbulence (or vertigo), but for the nominal IMC conditions predicated here, it is assumed as about 50% workload. The exact percentage is dependent on many factors, but it is reasonable to assume, for the purposes of this discussion, that an IFR certified helicopter exists that can be flown properly by an experienced pilot in IFR enroute conditions and using about 50% of his capability just to fly the aircraft on instruments. He chooses to keep in reserve some portion of his total flight control workload capability (15%) for unexpected flight control problems or emergencies but nevertheless, he still has about one third (35%) of his total workload capability open or non-dedicated.

It is assumed in this enroute case that the special conditions, environment, navigation, communications, and ATC activities are such that the workload level associated with these auxiliary tasks is classed as high. It is a flight conducted in conditions where the traffic density is high, where radar coverage, if it exists, does not

CASE I

IFR ENROUTE FLIGHT PHASES
WITH HIGH AUXILIARY TASK WORKLOAD.

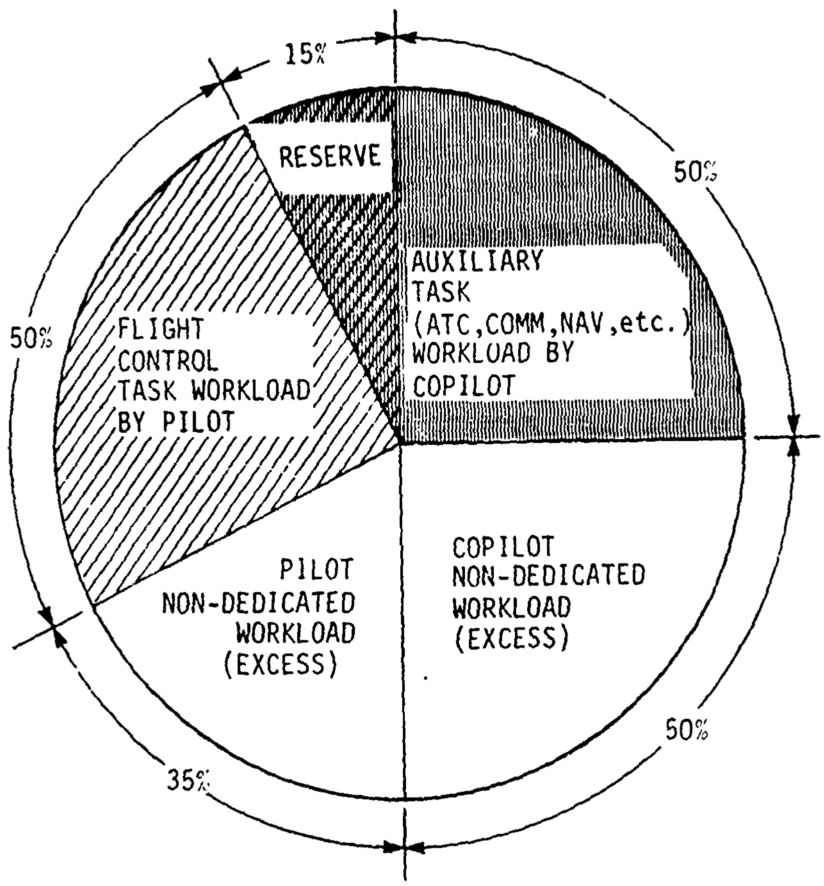


Figure 5-1. Depiction of Total Workload for Two-Pilot, Enroute IFR Flight Phases (Case I).

materially reduce the associated auxiliary tasks to a significant degree, and where generally there are sufficient clearance changes and/or requests from the ATC system to require the copilot to utilize about half his total workload capability just to accomplish all the auxiliary tasks on the enroute flight phases. He has about half his total workload capability open (non-dedicated) for other needs should they arise. (It is interesting to note for this case that Geiselhart's studies (Reference 5) estimate that the "desirable" workload level for an aircraft commander should not go over about 50 percent total.)

Both pilots are operating at a reasonably comfortable level for this normal-mode condition (no failures) with this particular helicopter. As far as the flight control performance/workload level of the pilot (handling-pilot) is concerned, he is not heavily involved, but his flight control inputs and techniques require that he continually correct the short term state of the aircraft. He is providing moderate compensation for this pilot/aircraft system and achieving adequate flight path control performance.

One-Pilot Operation

In Figure 5-2, the piechart of Figure 5-1 is shown for the same case but with no copilot on board the aircraft to perform the auxiliary tasks. The helicopter (and its inherent flying qualities) is the same one used in the example shown in Figure 5-1, except that now an attempt will be made to operate it with just one pilot instead of two. The case is still the enroute flight phases with high auxiliary task workload. The special conditions of weather and environment are the same as stated earlier.

In Figure 5-2 the pilot's flight control workload is shown as half (50%) and is identical to that portrayed in Figure 5-1 since it is still the same aircraft with the same flying qualities. Also, the pilot's reserve portion is shown as before. There is no copilot on board the aircraft, so the lone pilot must also perform the auxiliary task workload for this specific enroute case. Since the particular circumstances of the flight have not changed (only the copilot has been removed), the auxiliary task workload level formerly performed by the copilot (50%, Figure 5-1) is now added to the pilot's required workload level.

It may be argued that with the copilot removed from the aircraft, the auxiliary tasks for the lone pilot may be reduced slightly just due to some blending, overlapping, and reduction in the two different workload tasks. Admittedly, the ATC/COMM/NAV, etc., auxiliary task workload level may be reduced a little just due to the absence of the

CASE I

IFR ENROUTE FLIGHT PHASES
WITH HIGH AUXILIARY TASK WORKLOAD.

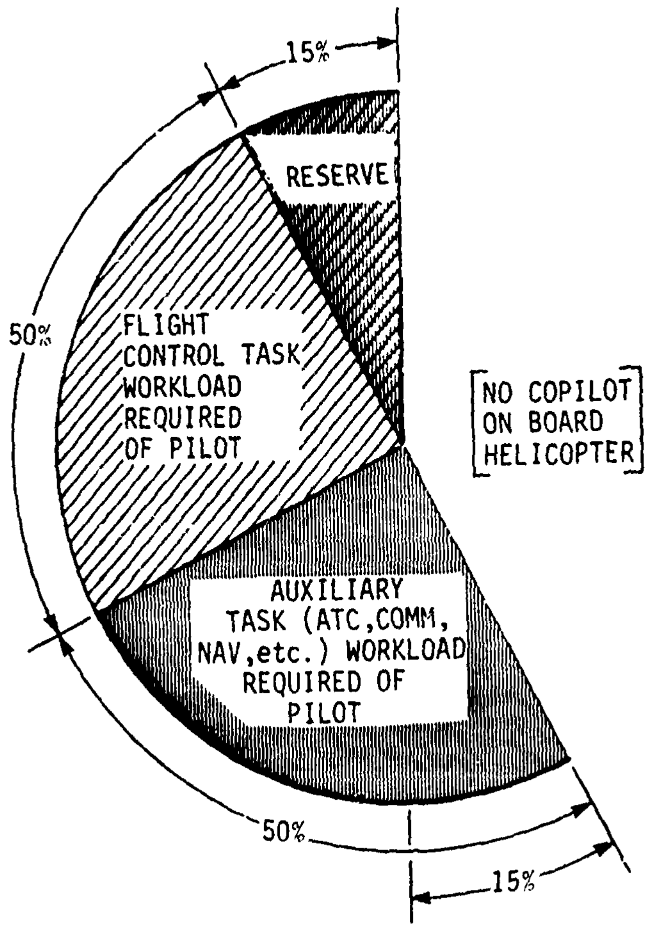


Figure 5-2. Depiction of Total Dedicated Workload for Two-Pilot, Enroute Case (1) Applied to One-Pilot Manning Level.

need for intercommunication and interaction with the copilot, but in reality the auxiliary tasks will probably be about the same as when two pilots were on board the aircraft.

With the aforementioned in mind and with reference to Figure 5-2, the pilot is required or needs to assume total control of the flight as the sole pilot on board the aircraft. He must perform the same flight control workload as before (50%, Figure 5-1) and also all the auxiliary task workload formerly performed by the copilot (50%, Figure 5-1). However, for this particular aircraft and task, he cannot perform at this workload level without intruding on his "RESERVE" and will reject the situation. Before, in the two-pilot case of Figure 5-1, the handling pilot was working at a flight control workload level of about half (50%) and was willing or had the capability to increase it to a maximum of about 85% (50% plus 35%, non-dedicated workload) without dipping into his reserve. Now he is faced with accepting an auxiliary workload level of 50% in addition to the flight control workload (50%). The sum of these two workload levels is shown in Figure 5-2 where the extra total workload level (15%) is shown extending into the right-half pie (copilot's side) and cannot be accomplished by the lone pilot without using the reserve.

Again, the exact percentages are not important here since the piecharts are only intended to show that this helicopter (for this enroute flight case and with its inherent flying qualities) may be satisfactorily flown with two-pilot aircrew manning levels but is unsatisfactory for one-pilot aircrew manning levels. For the one-pilot case, the total workload must be reduced to acommodate his capabilities. Since very little can be done to reduce the auxiliary workload significantly, the reduction usually is applied to the flight control portion of the total workload. Although a DME or multiple waypoint RNAV system may be installed to attempt to provide some reduction to the auxiliary tasks, workload relief is usually provided to the sole pilot with the addition of SAS (or SCAS) systems and/or autopilots with attitude-hold functions. The SAS systems and attitude-hold autopilots aid in reducing his flight control workload. This re-allocation of the pilot's available workload is shown in Figure 5-3 for the one-pilot manning level example. The encroachment of the auxiliary task sector into the territory representing the total workload capability of the pilot is depicted by rotating the 50% circular sector (representing the ATC/COMM/NAV etc., workload as shown in Figure 5-1) around in the clockwise direction until it is entirely on the pilot's side of the chart. Note that this is accomplished at the expense of the workload level available for the flight control task of the helicopter. For this single-pilot case, the workload capability of the pilot that can be apportioned to the flight control task is reduced to about one-third (35%) as compared to 50% utilized before for the same task when there was a copilot on board the aircraft. If this is to be a successful endeavor,

CASE I

IFR ENROUTE FLIGHT PHASES
WITH HIGH AUXILIARY TASK WORKLOAD.

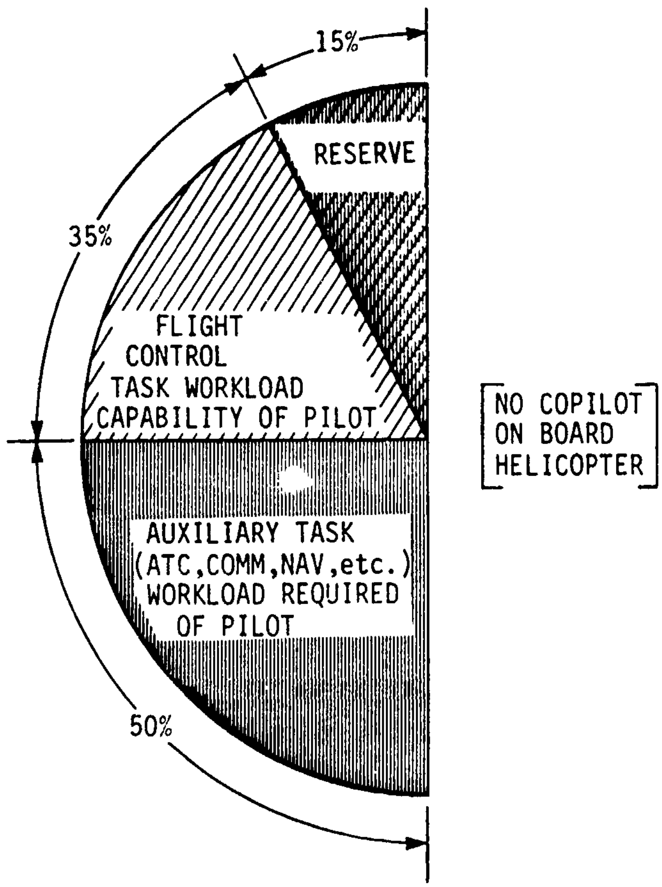


Figure 5-3. Depiction ot Total Workload Capability Modified for One-Pilot Manning Level for the IFR Enroute Flight Phases (CASE I).

the flying qualities of this particular helicopter will need to be improved so that the pilot's flight control workload will be reduced to the point where he can adequately and successfully participate in the accomplishment of all the needed auxiliary tasks without exceeding a tolerable total workload level or dipping into his reserve.

Of primary importance, in the dual and single pilot cases detailed above, is the determination that the examiner is forced to make concerning the "allowable workload level" that the pilot expends on flying or controlling the helicopter. The "allowable workload level" definition used for this section is that integrated physical and mental effort required to perform the specified flight control-piloting task. It is that portion of workload which is apart from that required for the ATC/COMM/NAV, miscellaneous cockpit duties, writing clearances, managing or monitoring subsystems, etc.

Whether one accepts the illustrations made above concerning the approximated or assumed divisions of workload for the various examples as representative of typical IFR certification cases or not, the general message that should be noted is that the maximum allowable workload level SOLELY FOR THE CONTROL TASK OF FLYING THE HELICOPTER which can be safely accomplished by the Pilot-in-Command under single-pilot operations IS LESS THAN the maximum allowable workload level which can be safely accomplished by the Pilot-in-Command of dual-piloted aircraft, (Figures 5-1 and 5-3). When there were two pilots on board, the PIC could devote 50% (or up to as much as 85%) of his total available workload capability TO THE FLIGHT CONTROL TASK, (Figure 5-1). For the same flight phases and single-pilot operation, the PIC has the opportunity to allocate only about 35% of his total workload capability TO THE FLIGHT CONTROL TASK, (Figure 5-3).

It would be interesting to surmise what the allowable workload level means to the flight examiner, the handling qualities test-pilot and the stability and control engineer. In the first example, the dual pilot example of Figure 5-1, the Pilot-in-Command has the workload level (integrated physical and mental effort) available to fly a helicopter that responds to gusts continually, has considerable cross-coupling and is difficult to trim. He may sense a dutch roll response that niggles him and he detects a long period mode that he is unsure of but has the time and capability to handle or tolerate each adequately. He is required to provide moderate pilot compensation and although he is not heavily involved, he must continually correct the short term state of the aircraft.

In the second example, the single-pilot example of Figure 5-3, the workload capability he now has for the flight control task means that he cannot fly the same helicopter depicted in Figure 5-1 on a single-pilot IFR flight. He still possesses the the same basic skills and talents to do the same "total workload" flight control task when he had a copilot but now the encroachment of the auxiliary tasks (ATC/COMM/NAV, etc.) denies him the opportunity to allocate the needed or required flight control workload portion for that particular aircraft and handling qualities. (The total of the two workload parts, the flight control and the auxiliary workloads, will always equate to the same total workload capability he had when he devoted his attention and effort to only the flight control task of the two-pilot manning level aircraft.). The 35% shown in Figure 5-3 means that he no longer has the amount of available workload capability needed to perform the flight control task for that particular helicopter and flying qualities.

As the lone pilot on board the helicopter, he now needs an aircraft that is easy to control, does not respond readily to gusts and turbulence, has minor or no cross-coupling effects and is easy to trim accurately and quickly. It does not depart easily in the other axes, the dutch roll damping is acceptable and there is no undesirable long term motion. In order to provide such a system, the aircraft could have an attitude SAS (or SCAS) system and/or attitude-hold autopilot installed. Also, the PIC could have a display system which solves or ameliorates the problems of short and long term control placements (a Flight Director) and achieves an adequate level of flight path control and steering guidance. If needed, he may mitigate some of his auxiliary task workload problems by installing a multiple waypoint RNAV system and/or a DME system. In any event, with this system, although he is required to provide almost continual short and long term involvement in the control of the aircraft, his control techniques and involvement are relaxed and he is operating at a reasonable level of workload for the task at hand. Pilot compensation is at times minimal.

APPROACH FLIGHT PHASES (CASE II)

If the workload piechart is constructed to display the division of flight control workload versus the auxiliary task workload for the two-pilot, IFR, CAT I, ILS approach flight phases, it could appear as shown in Figure 5-4. The same special conditions of weather and environment detailed previously still apply for this case. Also, the definitions, descriptions, and discussions on performance/workload interdependence, and the adequate performance guideline (Table 4-1) are utilized again for these examples.

Two-Pilot Operation

In Figure 5-4, the piechart shows that the Pilot-in-Command (the handling pilot) is flying a helicopter whose overall handling qualities are such that he utilizes about three-quarters of his total available workload capability for the flight control task for this aircraft in the IFR, CAT I, ILS Approach flight phases. The handling pilot desires to keep his workload level high because he attempts to achieve the performance accuracies necessary to make a successful approach and landing for the special conditions of weather and environment prevailing. The pilot may have a small excess, non-dedicated portion of workload available (in addition to his reserve) for additional duties. It could also be argued that in order to assure a high success rate and proper tracking performance commensurate with the circumstances of CAT I approaches, that the handling pilot, when "close-in" on the approach, will saturate himself with a high level of flight control workload (85%) and subordinate, where possible, all other tasks in order to obtain or exhibit the highest proficiencies and efficiencies associated with difficult CAT I approaches. Depending on many factors, either examples are possible and reasonable.

As in the dual-pilot, Case I discussed earlier (Figure 5-1), the copilot is responsible for handling all auxiliary tasks on the approach. Since auxiliary task workload is quite variable during the approach, it is assumed that the copilot will utilize an average of about one-third (35%) of his total available workload capability on the approach. As the approach continues both pilots may subordinate certain tasks in favor of concentration on those tasks that will tend to assure a safe, accurate, and successful approach and landing. In this way, the copilot probably assumes an additional auxiliary task over and above the usual auxiliary task workloads associated with NAV/COMM/ATC, selection of systems, management of subsystems, etc. This additional auxiliary task workload accepted by the copilot is associated with his activities in monitoring the approach quality, safety, and performance of the handling pilot and also "looking-out" for IMC/VMC transition as the aircraft approaches the decision height. Therefore, he can alert the pilot on

CASE II

IFR, CATEGORY I, ILS APPROACH FLIGHT PHASES.

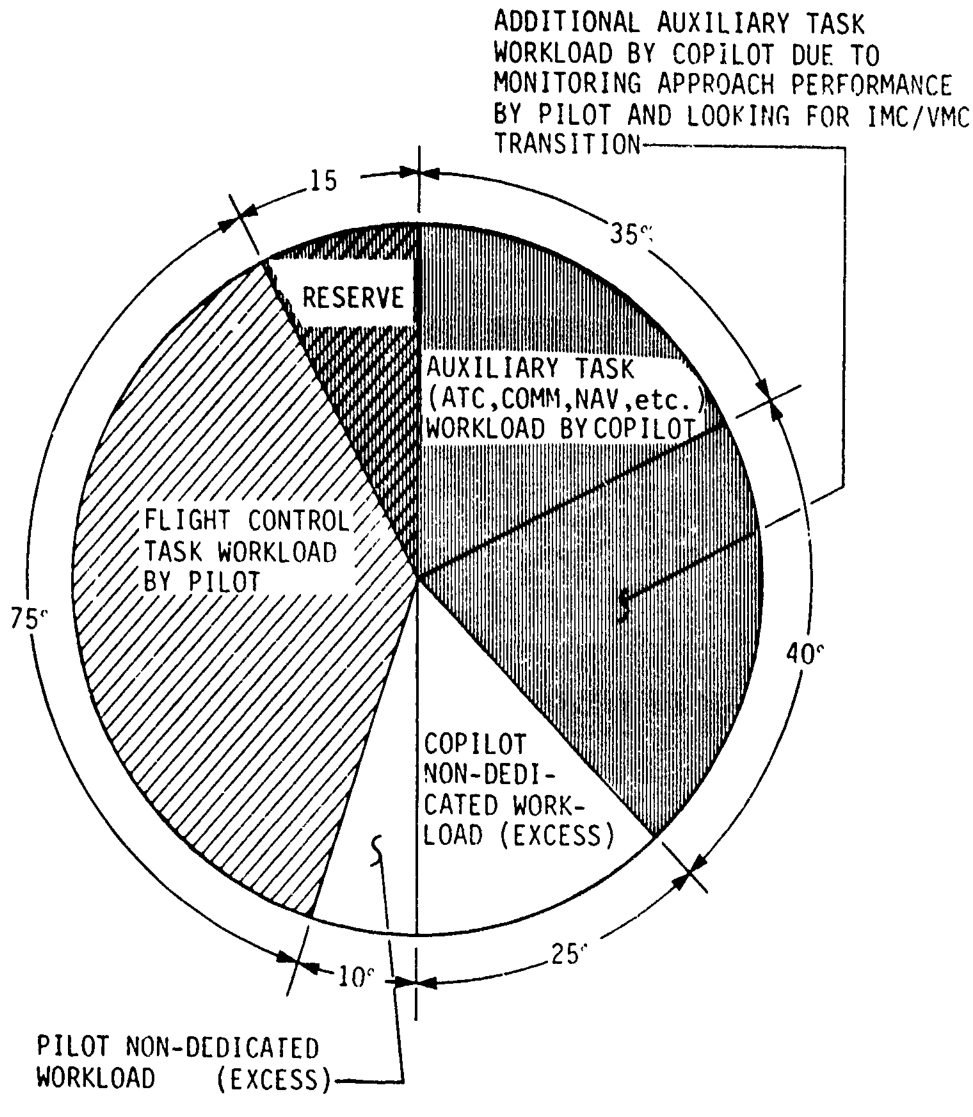


Figure 5-4. Depiction of Total Workload for Two-Pilot, IFR, CAT I ILS-Approach Flight Phases (CASE II).

any blunders or unusual conditions of the approach as well as provide a second set of eyes during transition to VMC conditions for the flare and landing. Figure 5-4, shows that these two combined auxiliary tasks may average as much as three-quarters (35% plus 40%) of his total workload capability. Again, he may choose, for safety reasons, to saturate his workload capability completely with the monitoring tasks as the approach commences to the critical points (where presumably the ATC/NAV/COMM tasks taper off for a time) in order to assist and enhance the quality and safety of the approach. If a missed approach is made, he aids the handling pilot by accomplishing all the auxiliary tasks necessary for a safe, proficient procedure.

As far as the PIC is concerned, he is busy and working pretty hard for this high-precision, high-performance task but he is functioning about as expected for this mission and well satisfied with the system operation. In fact, the aircrew may have some excess capability available which they consider normal and desirable for this particular situation. The PIC enjoys the challenge of the approach and the little excess workload capability permits him to adjust for occasional performance lapses or have time to make extra corrections or judgments without dipping into his reserve workload. He is working considerably harder in this dual-pilot approach case as compared to the flight control workload associated with the enroute case of Figure 5-1. However, the pilot needs to fly at this relatively higher, but satisfactory, workload level for only about 5-10 minutes and is achieving adequate performance commensurate with the objectives of a CAT I approach. Also, he has the added assurance and safety provided by the copilot and is not being asked to exhibit exceptional skill, alertness, and controllability. He is achieving adequate flight path control performance (Table 4-1) and is providing considerable pilot compensation. The pilot is heavily involved with the flight control task and he would not intentionally plan to encounter this level of effort for more than 5 or 10 minutes on a CAT I, ILS type approach.

<u>One-Pilot Operation</u>

In Figure 5-5, the piechart of Figure 5-4 is shown for the same case but with no copilot on board the aircraft to perform the auxiliary tasks. The helicopter (and its inherent flying qualities) is the same one used in the example shown in Figure 5-4 except that now an attempt will be made to operate it with just one pilot instead of two. The case is still the one represented by the IFR, CAT I ILS approach flight phases. The special conditions of weather and environment are the same as mentioned previously (in Case I).

CASE II

IFR, CATEGORY I, ILS APPROACH FLIGHT PHASES.

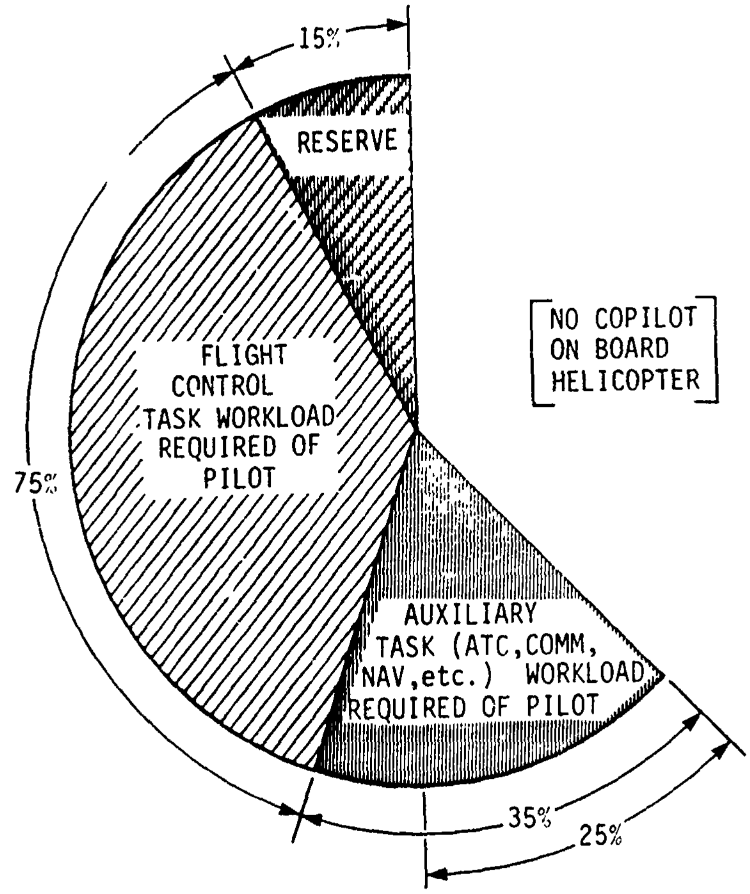


Figure 5-5. Depiction of Total Dedicated Workload for Two-Pilot IFR, CAT I ILS-Approach Case (II) Applied to One-Pilot Manning Level.

In relation to the auxiliary flight tasks performed by the copilot, there is one significant difference when the copilot is not on board the aircraft. The additional auxiliary task workload performed by the copilot and due to his monitoring approach quality and looking out for IMC/VMC transition (as depicted by the 40% portion of auxiliary task in Figure 5-4) is not transferable to the pilot. This is obvious and it should be noted that the added safety and enhancement to the approach due to this copilot workload is not present in the single pilot case and is simply deleted from the argument here. However, the other auxiliary task workload associated with ATC/COMM/NAV etc. (35%) is needed and required to be accomplished by the pilot for this example. This portion of the auxiliary task workload is quite variable during the various sub-phases and segments of the approach. Frequently, as the approach progresses, many of the auxiliary tasks will be subordinated or not needed since the pilot will concentrate most of his effort and attention on the flight control task in order to achieve the highest quality CAT I approach. If he needs to execute a missed approach, the auxiliary tasks associated with ATC/NAV/COMM, selection of systems, chart reading etc. could again take up a considerable portion of his total workload capability as they did in the enroute phases.

Therefore, Figure 5-5 depicts the auxiliary task workload associated with the ATC/COMM/NAV etc. duties (35%) added to the flight control workload (75%) for the helicopter depicted in Figure 5-4. The sum of these two workloads is shown in Figure 5-5 where the extra total workload level (25%) is shown extending into the right-half pie (copilot's side) and cannot be accomplished by the lone pilot. As before, in Case I, the exact percentages are not important here since the piecharts are only intended to show that this helicopter (for this approach flight case and with its inherent flying qualities) may be satisfactorily flown with two-pilot aircrew manning levels but is unsatisfactory for one-pilot aircrew manning levels.

The same workload relief methodologies mentioned for the similar example of Case I may again be applied. The re-allocation of the pilot's available workload is shown in Figure 5-6 for the one-pilot aircrew manning level example. As before, the encroachment of the auxiliary task sector (35%, ATC/COMM/NAV etc.) into the territory representing the total workload capability of the pilot is depicted by rotating that sector around in the clockwise direction until it is entirely on the pilot's side of the chart. This is again accomplished at the expense of the workload level available for the flight control task of the helicopter. Since this significantly reduces his participating in the flight control task during portions or segments of the approach (or missed approach), the flying qualities of this helicopter will have to be improved as compared to those depicted for the dual-piloted helicopter of Figure 5-4. The same general message of Case I

CASE II

IFR, CATEGORY I, ILS APPROACH FLIGHT PHASES.

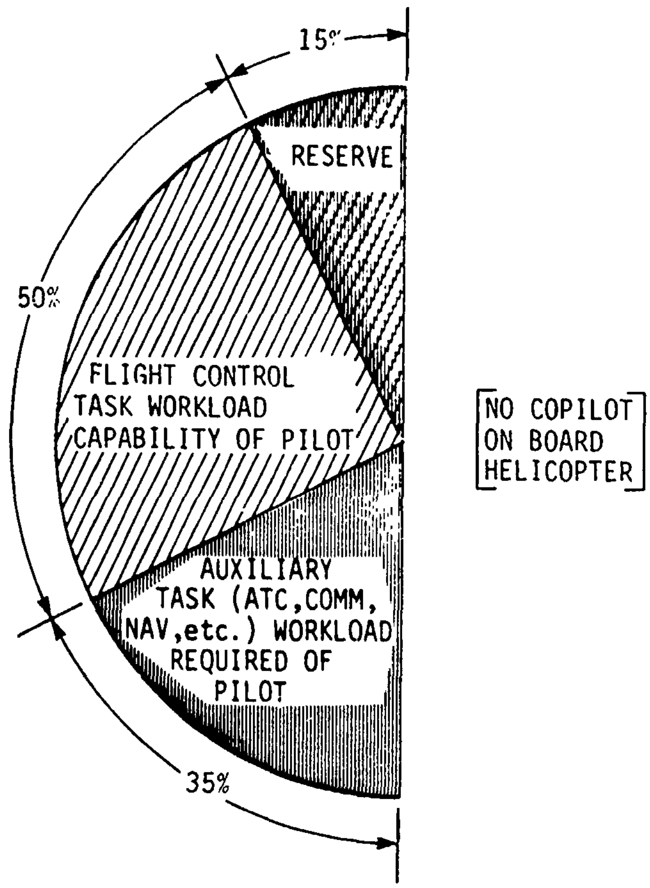


Figure 5-6. Depiction of Total Workload Capability Modified for One-Pilot Manning Level for the IFR, CAT I ILS Approach Flight Phases (CASE II).

is noted here also; namely, the maximum allowable workload level SOLELY FOR THE CONTROL TASK OF FLYING THE HELICOPTER which can be safely accomplished by the Pilot-in-Command under single-pilot operations IS LESS THAN the maximum allowable workload level which can be safely accomplished by the Pilot-in-Command of dual-piloted aircraft, (Figures 5-4 and 5-6). Also, with no copilot on board, the monitoring of the approach and the sighting by the co-pilot for VMC conditions as the aircraft approaches the decision height is not accomplished.

In the first example, the dual pilot example of Figure 5-4, the Pilot-in-Command has the workload level (integrated physical and mental effort) available to provide considerable compensation and is heavily involved in the flight control task. In the second example, the single-pilot example of Figure 5-6, the workload capability the pilot now has for flight control means that he cannot fly the same helicopter depicted in Figure 5-4 on a single-pilot IFR flight. The 50% shown in Figure 5-6 (and compared to the 75% in Figure 5-4) indicates that he needs a helicopter with better flying qualities, where only moderate pilot compensation is required. As the lone pilot on board and since he is flying the approach phase where he is closely controlling the aircraft, and has limited or subordinated some of the auxiliary tasks, the PIC needs a helicopter where only moderate pilot compensation is required. He is not heavily involved in the flight control task though he must continually correct the short term state of the aircraft. As in Case I, the lone pilot needs a degree of workload relief as provided by systems such as SAS, SCAS, Flight Directors, Attitude-hold autopilots, and/or RNAV, DME type systems.

SUMMARY

Although the foregoing discussions and illustrations may appear to be rather basic, and the findings obvious to some from the beginning, the intent of the section was to provide:

- a rationale or fundamental basis for the division of the aircrew workload into two parts -- flight control and auxiliary workload.
- a more structured approach or insight and understanding of the numerous variables, facets, methodologies and logic utilized in the determination of acceptable workload level for the minimum aircrew.
- a systematic approach to the impact and effects due to changes in minimum required aircrew manning level (two-pilot versus one-pilot).
- a better understanding of the importance of the determination of acceptable workload level for individual aircrew members when establishing the minimum required crew as related to the IFR certification process of helicopters.
- a series of examples that depict the role and need of pilot workload relief systems, such as stability augmentation, automatic pilot type devices with attitude-hold type basic functions and additional avionics like DME or preprogrammed multiple waypoint RNAV, for one-pilot IFR certifications.

The need to examine all the critical cases for IFR certification of helicopters was emphasized. In addition to the importance of analyzing the critical stability and control cases (aft c.g., high power/high vertical rate of climb, minimum approved airspeed, etc.), the importance of carefully analyzing the pilot workload aspect of IFR certification in the most critical cases was explained. These workload critical cases include selection of those flight phases that most represent the critical workload arena as well as stipulation of special conditions and environment. The stipulations of special conditions and environment include such items as weather, turbulence, wind shear, night, crosswind, stress, ATC activity and traffic density, and terminal type.

During the division of workload into two groups (flight control and auxiliary) and in relation to the total workload capability versus aircrew manning level, a fundamental, basic premise was determined; namely, that the maximum allowable workload level SOLELY FOR THE CONTROL TASK OF FLYING THE HELICOPTER which can be safely accomplished by the Pilot-in-Command under single-pilot operations IS LESS THAN the maximum allowable workload level which can be safely accomplished by the Pilot-in-Command of dual-piloted aircraft.

SECTION 6

FLIGHT MANEUVER PATTERNS

INTRODUCTION

In section 3, the Composite Helicopter IFR Flight Profile (which was originally developed in Reference 1) was introduced as representative of typical helicopter IFR operations. It is usable by the analyst in developing elements of a workload evaluation scheme that is applicable to the process of certification of helicopters for IFR flight. The Composite Profile was analyzed to approximate the pilot effort available for the flight control task. Section 4 developed performance objectives for IFR operations which a helicopter instrument pilot should be expected to achieve.

As noted in Section 2, of this report, paragraph (j) of the Interim Criteria stipulates that a rotorcraft must be flown in the ATC system under actual IFR conditions for at least five hours, "... without undue pilot fatigue or exceptional pilot skill and alertness", and to evaluate "... In-Flight IFR workload demands on the minimum required flight crew." Obviously this flight is required for a real world evaluation of "man" workload and "man-machine" performance.

This section presents two flight patterns which are offered as surrogates of the Composite Profiles developed in Section 3. One profile addresses departure and enroute maneuvers while a second profile addresses approach and missed approach maneuvers. These IFR Evaluation Patterns are offered as standard tasks for the evaluation pilot to accomplish for the purpose of determining the man-machine capability to meet the stated performance objectives within allowable workload limits. They are not intended to replace any elements of the certification process, but to provide a supplementary assessment tool.

DEVELOPMENT OF FLIGHT MANEUVER PATTERNS

In Reference 1 it was found that, when the many different operational roles of civilian helicopters were considered, each helicopter must be prepared to contend with all events contained in a typical IFR flight (e.g., the Composite Helicopter IFR Flight Profile which was developed for Reference 1). That Composite Profile is presented in Section 3, and includes all probable events of a non-emergency nature. They are based on two sources: (1) the services offered, and/or requirements of, the ATC/IFR environment as it exists today; and (2) contemporary flight techniques as taught and as practiced in the actual helicopter IFR environment.

A narrative was developed for Section 3 to summarize the activities and events for each flight phase of the Composite Profile. It states both flight control tasks and auxiliary tasks in a general sense to provide a basis for development of flight patterns which: first, relate to civil helicopter IFR applications and, secondly, are usable as a basis for standardizing maneuvers to be used in evaluating helicopters for IFR certification. The narrative summaries are presented in Appendix B.

A review and analysis of each flight phase of that narrative summary was conducted to identify all those flight maneuvers required during the execution of the composite helicopter IFR flight. Although the Composite Profile in itself appears complex, the actual flight maneuvers required for its performance are reasonably standard. The only major differences from one flight phase to the next were the sequence in which they were to be executed and the varied combinations of the same distinct maneuvers. The analysis of maneuvers was summarized (see Figure 6-1) and it became apparent that only two separate flight patterns would be needed to duplicate all the maneuvers required to execute the Composite Helicopter IFR Flight Profile: (1) Departure and Enroute, and (2) Approach and Missed Approach.

Airspeeds for the patterns were selected to approximate those most likely to be used by civilian operators. Slow Cruise (Maximum Endurance Speed) would be used primarily during holding patterns, especially when pilots are close to destination and concerned with fuel consumption. Fast Cruise (Maximum Continuous Power Speed) is most likely to be used enroute, when no turbulence is evident, since it is the most cost effective of the speeds for helicopters. Turbulence Penetration Speed is that speed recommended by the airframe manufacturer and could be necessary during any of the Composite Profile flight phases at one time or another.

	Takeoff	IMC Climbout	SID	Climb Enroute	Cruise Enroute	ATC Vectors (Wx)	Climb Enroute	Descend Enroute	Hold Enroute	STAR	ATC Vectors (FAC)	Hold at IF	Intmdt Approach	Final Approach ILS	Final Approach Non-Prec.	GO-AROUND @ MAP	IMC Climb	Intercept Radial	Climb on Course	Hold at Intxn
CONSTANT AIRSPEED																				
• Straight and Level			•		•	•			•	•	•	•	•							•
• Climb on Course		•	•	•	•	•	•		•								•		•	•
• Descend on Course					•	•		•	•	•	•	•	•	•	•					•
LEVEL TURNS																				
• Half Standard Rate	•		•		•					•	•		•	•	•					•
• Standard Rate			•		•	•			•	•	•	•	•							•
CLIMBING TURNS																				
• Half Standard Rate	•	•	•	•		•	•		•								•	•	•	•
• Standard Rate	•	•	•	•		•	•		•								•	•	•	•
DESCENDING TURNS																				
• Half Standard Rate								•	•	•	•	•	•	•	•	•				•
• Standard Rate								•	•	•	•	•	•							•
LEVEL OFF (FROM)																				
• 500 fpm Climb			•		•	•	•		•								•	•	•	•
• 500 fpm Descent						•	•	•	•	•	•	•	•	•	•					•
• Hi-rate Climb		•	•				•		•								•	•	•	•
• Hi-rate Descent								•	•	•	•	•			•					•
ACCELS/DECELS																				
• Straight and Level					•	•			•	•	•	•	•							•
• Climbing	•	•		•		•	•		•								•	•	•	•
• Descending						•		•	•	•	•	•	•							•
VERTICAL SPEED RATE																				
• Increase Climbing	•	•	•	•		•	•										•	•	•	•
• Decrease Climbing		•	•	•		•	•										•	•	•	•
• Increase Descending								•	•	•	•	•	•	•	•					
• Decrease Descending								•	•	•	•	•	•	•	•					
• Descent to Climb														•		•				
• Climb to Descent																				
• Level to Climb							•													
• Level to Descent								•		•	•	•	•	•	•					
CONFIGURATION CHANGE																				
• Gear Retract	•	•															•			
• Gear Extend												•	•	•	•					

Figure 6-1. Analysis of Flight Maneuvers Required for Composite Helicopter IFR Flight Profile.

Turns to both left and right were included for the various airspeeds and climb and descent conditions in an effort to accomodate the potential for lateral/directional stability and control asymmetries among different helicopters. The Patterns developed are discussed below:

The Departure and Enroute IFR evaluation pattern (Figure 6-2) duplicates all maneuvers required for the departure and enroute segments of the Composite Profile for both Fast Cruise and Slow Cruise, while accomodating appropriate accelerations and decelerations. Maneuvers required for all flight phases from IMC Climbout to Hold at IF (Intermediate Fix) are accounted for.

The Approach and Missed Approach IFR evaluation pattern (Figure 6-3) accounts for maneuvers required for all other flight phases, from Intermediate Approach to Hold at Intersection following Missed Approach. Some of the maneuvers utilized in the first Pattern were used again here, allowing for their duplication at Turbulence Penetration Speed (TPS). This pattern was developed so as to simulate as closely as possible an actual precision approach, including left and right turns of 15 and 30 degrees during a simulated final approach segment to duplicate the possible corrections necessary to initially establish wind drift corrections required to track the localizer course. Of importance in this pattern is the Go-Around point at which the transition is made from a relatively steady-state descent of approximately 500 fpm to a high-power, high rate of climb, or to the maximum allowable IMC climb rate certified. At the conclusion of the pattern, an additional go-around is recommended from 50 knots (or minimum allowable IMC airspeed) and 250 fpm descent.

While the patterns may appear to be both cumbersome and time consuming at first glance, the need for thoroughness in any aircraft certification dictates the development of patterns which are comprehensive. It should be re-emphasized here, that in no way are these patterns intended to replace any test elements of the current certification methods. Rather, they are envisioned as supplementary workload assessment tools to the existing process.

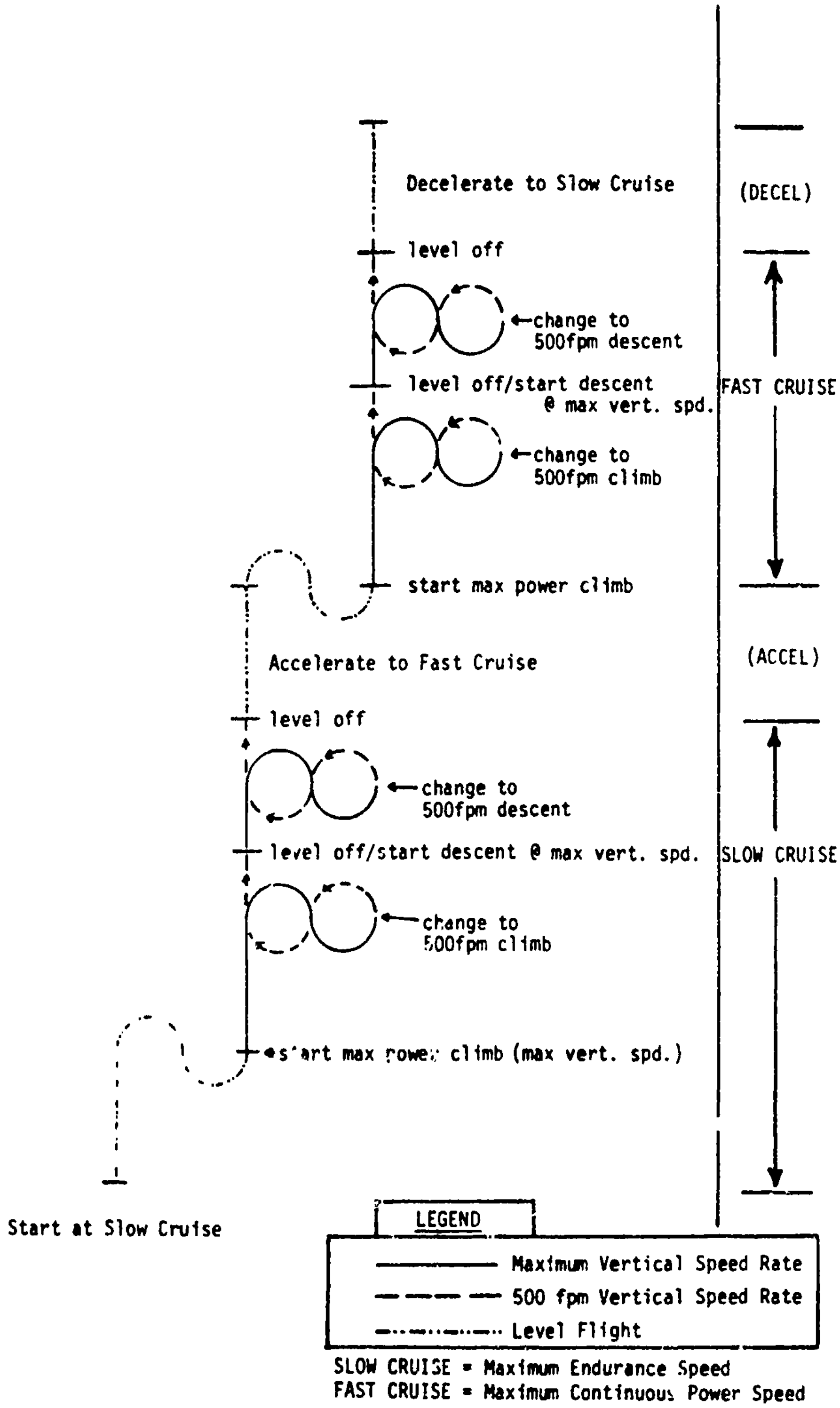


Figure 6-2. IFR Evaluation Pattern: Departure and Enroute.

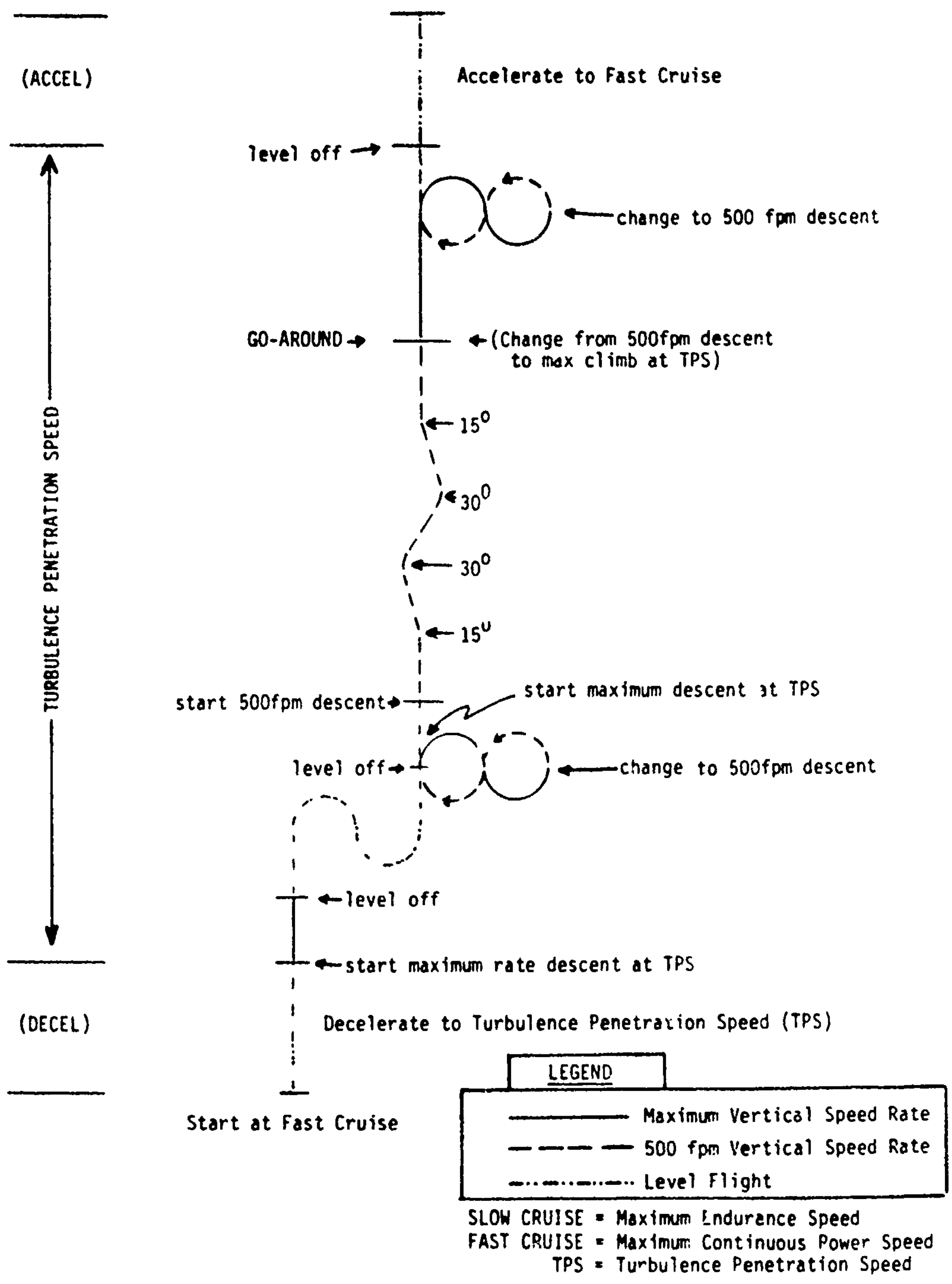


Figure 6-3. IFR Evaluation Pattern: Approach and Missed Approach.

SECTION 7

DISCUSSION OF A WORKLOAD EVALUATION SCHEME

INTRODUCTION

This section describes a workload evaluation scheme that can be applied to the current FAA instrument certification process for helicopters. The proposed scheme observes the constraints stated earlier while utilizing the results and findings developed throughout the preceding sections.

In summary, Section 2 of this report defined aircrew workload as consisting of two parts: flight control workload and auxiliary task workload; and described the relationship of these two parts to the IFR certification process. Section 3 identified the flight control and auxiliary tasks associated with specific segments of IFR flight and quantified auxiliary task requirements using time-line analysis methods. Section 4 delineated performance objectives for IFR flight and predicated the interdependence of performance and workload. Section 5 discussed the workload/performance implications for single and dual pilot operations as related to the IFR certification process. Section 6 developed maneuver patterns offered for use as appropriate assessment tasks to be used by evaluation pilots in determining the suitability of the pilot workload levels required to fly the aircraft.

GENERAL

As stated in numerous Federal Aviation Regulations and other government standards and criteria (Section 2), there is a requirement to consider the workload of individual crewmembers in order to establish the minimum required flight crew needed for safe operation of an aircraft within the National Airspace System. In order to fulfill this mandatory requirement, actual flight testing is accomplished. The FAA examiner is required to make a judgment on whether or not the workload level of the minimum crew (individually rated) is acceptable for the specific aircraft, under the objectives of the certification requested.

Precisely, what the specific "pilot workload criteria" are and how they are to be evaluated or appraised has not been well documented in the past. For example, one easily accessible document on Transport Category Airplanes (FAR, PART 25, APPENDIX D), appears to address the matter most pertinently but even that Appendix provides little, if any, guidance on the evaluation methodologies, appraisal procedures and workload level descriptors that determine acceptability and compliance, (with the exception of other FAR sections stating that the aircraft "... must be able to be flown without undue pilot fatigue or strain, in any normal maneuver for a period of time as long as that expected in normal operation."). Yet Appendix D (PART 25) requires that even such general, basic functions as the pilot workload level needed for the flight path control task be considered and analyzed (PART 25, Appendix D, paragraph a,1).

Auxiliary tasks and other workload factors are also considered to be significant and are required to be analyzed. Some of the items mentioned in that FAR are (as excerpted in part):

- "The degree and duration of concentrated mental and physical effort involved in normal operations and in diagnosing and coping with malfunctions and emergencies.
- The degree of automation provided in the aircraft systems ...
- The communications and navigation workload.
- The possibility of increased workload with any emergency that may lead to other emergencies."

The subject of evaluating, judging, and quantifying an acceptable level of pilot workload and establishing the minimum required flight crew for an aircraft in order to comply with existing regulations continues to be a controversial and essentially unresolved area for certain aircraft. Even with some current airplanes (where the tasks and levels of workload are apparently well known), the issues of minimum flight crew and pilot workload criteria are still in some cases, unresolved (Reference 15).

Reference 15 is also interesting because it documents continuing efforts to resolve these minimum aircrew manning level issues even for aircraft that have been in operation for a long time. The aircraft under discussion there is a modern civil airplane used extensively (almost 10 million landings to date) in current air-carrier operations. According to that reference, regul..tory criteria are used to "approve cockpit staffing based on workload of the individual aircraft, taking a separate look at each one." The reasons for the study of the addition of an extra aircrew member seem to center on workload and related safety and/or failure-mode/emergency operation considerations.

Considering the recent increase in both the new models of all sizes of helicopters and the apparent desire to fly them under IFR conditions, the subject of minimum required flight crew and pilot workload appraisal continues to be an important area of study. Given the current regulations, requirements, and criteria (FAR 27.1523, 29.1523, Interim Criteria, paragraph j, etc.), the determination of compliance for this subject area can be aided by the development of a documented or structured workload evaluation scheme. In order to initiate a preliminary scheme, numerous subject areas such as pilot/vehicle handling qualities, performance objectives, certification goals (such as IFR, CAT I, ILS), and aircrew manning level (one-pilot, two-pilot, etc.) must be addressed. The discussions offered in the previous sections of this report and the following material, thus support the development of a candidate workload evaluation scheme offered in the following paragraphs.

ESTABLISHING A WORKLOAD EVALUATION SCHEME

As summarized briefly in the Introductory part of this section, the previous sections of this report established some initial conditions and discussed a variety of topics related to workload evaluation for IFR certification of helicopters. Some of the conditions and findings that may be derived from the preceding sections are listed below and are utilized as a starting basis for framing and establishing the evaluation scheme:

- Regulatory requirements were identified that require;

    1. Establishment of the minimum flight crew sufficient for safe operation,

    2. Consideration (and judgment) of (acceptable) workload level on individual crewmembers,

    3. Evaluation of the ability to operate the rotorcraft satisfactorily under (actual) IFR conditions in the air traffic control system without undue pilot fatigue or exceptional pilot skill or alertness,

    4. Evaluation of the handling of the rotorcraft in rough air turbulence,

    5. Evaluation of the in-flight IFR workload demands on the minimum required flight crew.

- Two critical flight phases pertinent to the IFR certification process and essential for flight-test consideration in the evaluation of pilot workload were selected and defined, namely;

    1. IFR, Enroute flight phases -- for the case in which high auxiliary task workload levels are encountered.

    2. IFR, Category I, ILS Approach flight phases in which high flight control task workload levels are encountered.

- Total workload for the minimum required aircrew may be divided into two categories and are defined as:

    1. Flight control task workload.

    2. Auxiliary task workload.

- When the workload required solely for the control task of flying a helicopter is considered; the maximum allowable flight control workload level which can be safely accomplished by the Pilot-in-Command under single-pilot operations is less than the maximmum allowable flight control workload level which can be safely accomplished by the Pilot-in-Command of dual-piloted aircraft.

- For one-pilot certifications, if workload relief is required it is typically provided by means such as stability augmentation systems, and/or automatic stabilization functions like the attitude-hold feature of an autopilot, and/or additional avionics or displays (i.e., DME etc.).

- Depending on the handling qualities of each specific helicopter (e.g. stability and control, displays, task etc.), the pilot will need to provide the appropriate COMPENSATION (added flight control effort and attention) required to achieve stated PERFORMANCE goals.

- The total flight control workload is the sum of the workload due to COMPENSATION (for the handling qualities deficiencies of the helicopter) and the workload due to the task.

- Auxiliary tasks exist which can draw a pilot out-of-the-loop for periods from 10 to 90 seconds.

- A high concentration of auxiliary tasks can be imposed for periods of up to five minutes, during some flight phases.

- The strong interdependence between workload required and performance achieved is recognized.

- Flight path control performance objectives were identified. They reflect the performance required under Instrument Meteorological Conditions to insure a level of safety. The objectives were defined as the ADEQUATE PERFORMANCE GUIDELINES and are listed in Table 4-1. Only this particular set of performance guidelines are utilized in this section. Therefore, the performance objectives are held constant but the acceptable flight control workload is allowed to vary for each case, as a function of the task.

- The importance of SPECIAL CONDITIONS and ENVIRONMENT (weather, turbulence, night, high traffic density, stress, etc.) to the IFR certification process is recognized.

When the large matrix of variables and conditions (consistant with the findings stated above) are considered, a typical table can be constructed that takes into account the different flight phases, minimum aircrew manning levels and operational modes (normal-mode or failure-mode operations) versus the allowable flight control workload limits required for compliance with the regulations. The format of this table is shown below:

TABLE 7-1

FORMAT FOR MAXIMUM ALLOWABLE FLIGHT CONTROL WORKLOAD LEVEL

	ONE-PILOT		TWO-PILOT	
	ENROUTE	APPROACH	ENROUTE	APPROACH
NORMAL MODE				
FAILURE MODE				

NOTE: Each of the eight open blocks inside this table represents a task or evaluation condition defined by: a particular flight phase (enroute or approach), aircrew manning level (one-pilot or two-pilot), and aircraft state (normal-mode or failure-mode operations).

From examination of the regulatory documents, it can be postulated that the object of the FAA certification process is a product which will provide a level of safety for instrument helicopter operations. It appears that it is within the purview of the FAA (and their flight test examiners) to require that adequate performance objectives can be be achieved by the pilot/vehicle system. A readily available document utilized as a flight test guide for instrument ratings for helicopter pilots (Reference 14) provides specific performance objectives for all phases of instrument flight in a helicopter. The performance objectives stated in that advisory circular are summarized in Table 4-1 of this report and are defined as the adequate performance guidelines utilized in the development of the workload evaluation scheme of this section.

Also, the impact of SPECIAL CONDITIONS such as weather must be reconsiderd if extremes occur. For example, although a nominal-bad, IMC day was assumed for purposes of this report, extreme degradation in weather conditions (i.e., extreme turbulence and severe crosswinds) would naturally have a deleterious effect on the pilot/ vehicle system, especially the workload/performance factors. Extreme weather degradation can be accounted for in applying workload limits by assuming that increased pilot compensation is necessary. For guidance, one might assume one increment or one step increase in workload (yet to be defined) would be allowed for extreme weather. The effect is briefly addressed again, later in this Section.

For the reasons stated in the conditions and findings of this section and in conformance with the format developed for Table 7-1, there is a need to establish workload limits in the form of descriptors of flight control workload that define different levels of pilot effort and attention required to achieve the adequate performance guidelines discussed earlier. Each of these descriptors should include brief additional remarks that would aid the test pilot in distinguishing the different levels of compensation required for different flight control tasks: by the flight objective, aircraft state (normal-mode or failure-mode), and manning levels.

A set of flight control workload descriptors was developed as a result of this effort. One discrete descriptor was developed for each of the discrete workload tasks illustrated in Table 7-1. These descriptors are presented in Table 7-2. The introductory paragraph, included in Table 7-2 and enumerated by (1), is inserted to provide typical phraseology for inclusion of these descriptors into advisory material or as criteria. When these descriptors are properly assigned to the tasks of Table 7-1, the finished result is Table 7-3. That is, the workload descriptors of Table 7-2 are shown in Table 7-3, properly matched with the different flight phases, operational mode, and aircrew manning levels as formulated in Table 7-1. The numbers identify the workload descriptor which describes the maximum workload which can be observed and found acceptable for FAA certification.

TABLE 7-2. WORKLOAD DESCRIPTORS

(PILOT'S EFFORT AND ATTENTION REQUIRED FOR THE FLIGHT CONTROL TASK)

1. For IFR certification of helicopters, adequate flight path performance guidelines stipulated in Table 4-1 shall not require pilots to exceed the workload limits stated below for the applicable conditions specified in Table 7-1:

1.1 Minimal pilot compensation. Control techniques are relaxed. Continual pilot involvement in short and long term flight control task.

1.2 Moderate pilot compensation. Pilot is moderately involved in the flight control task, and must continually correct the short term state of the aircraft.

1.3 Considerable pilot compensation. Pilot is heavily involved in the flight control task. The pilot would not intentionally plan to encounter this level of effort for more than 5-10 minutes.

1.4 Extensive pilot compensation. Pilot is very heavily involved in the flight control task. The pilot would not intentionally plan to encounter this level of effort.

1.5 Maximum pilot compensation. Pilot is totally involved in the flight control task. The pilot would not intentionally plan to encounter this level of effort.

TABLE 7-3

MAXIMUM ALLOWABLE FLIGHT CONTROL WORKLOAD LEVEL

(Using descriptors of Table 7-2 for conditions of Crew Level, Flight Phase, and Operational Mode)

	ONE-PILOT		TWO-PILOT	
	ENROUTE	APPROACH	ENROUTE	APPROACH
NORMAL MODE	1.1	1.2	1.2	1.3
FAILURE MODE	1.2	1.3	1.3	1.4

1.5 NOTE: Applies to both one-pilot and two-pilot operations in either enroute or approach for failure modes which require an unacceptable degree of pilot workload and/or do not permit the flight to continue as intended; or during which adequate performance objectives cannot be met.

NORMAL-MODE VERSUS FAILURE-MODE OPERATIONS

Table 7-3 provides guidance for allowable workload level limits for failure-mode operation as well as normal-mode operation. Defining the various failure modes is a complicated subject given the large variety and matrix of possibilities that exist. It is possible for a helicopter (especially the single-pilot vehicles) to contain systems and items such as (Reference 1):

- Simplex, Duplex, Triplex control system actuators (up to a total of three actuators per axis)
- Three axes of augmentation
- Simplex, Duplex, Triplex vertical gyro sources. (Up to three complete gyro packages for a Triplex system)
- Primary, Secondary, Battery-Only Electrical Systems
- Boost Systems (sometimes primary and secondary and failure modes)
- Single and Multiple Autopilot, Augmentation, Avionics, Control Computers, Amplifiers, and Control Panels, etc.

Paragraphs e and f of the Interim Criteria address failures and failure-mode operation with respect to artificial stabilization systems, artificial means, and engine failures as:

"(e) Artificial stability. If the basic rotorcraft utilizes artificial means to meet the stability requirements in paragraphs (b), (c), and (d) of the Appendix, the reliability of artificial means must be substantiated.

(1) An artificial means may be used without a backup or standby means provided the rotorcraft -

(i) With the means inoperative, has all of the flight characteristics specified in Subpart B of this Part and, in addition, has positive lateral, longitudinal, and directional stick position stability and is free from tendencies towards excessively rapid or dangerous divergence.

(ii) Can be flown IFR without undue difficulty by the minimum crew with the means inoperative for a length of time equivalent to the usable fuel supply of the helicopter, but in any event not less than one hour. If usable fuel capacity of the helicopter is increased after certification, the requirement of this subparagraph must be met with the new fuel capacity, or else the length of time established with the previous fuel supply must be applied (either in the flight manual or on a placard) as an operating limitation.

(2) If the conditions of subparagraph (1) of this paragraph are not met, an equivalent backup or standby artificial means must be provided. Careful consideration must be given to the manner (e.g., automatic or manual switching) in which the backup or standby means is activated when the primary artificial means fails or malfunctions.

(f) Controllability. Throughout the approved IFR airspeed range there may not be dangerous divergence and uncontrollable tendencies following a sudden failure or malfunction of the artificial stabilization means or following the failure of a powerplant.

The control authority of an automatic stabilization device may not be of such magnitude that in case of failure of the device, insufficient control remains with the pilot for maneuvering in both normal and emergency conditions."

Reference 3 provides a definition for failure-mode operation (Appendix A) and is stated as:

"FAILURE STATE - A steady-state failure characterized by the various failed systems that affect the handling qualities. The dynamic effect of a failure is called a change of state and should be noted separately.

Examples: Any failure resulting in loss of selected function. Engine failure, augmentation system, failure in stability, autothrottle, primary flight control system (power boost, electric stick, servo control feel, etc.) or secondary flight control system (trim, aerodynamic brake, etc)."

When a failure occurs, the pilot must evaluate the seriousness of the failure and determine which option or alternative should be exercised:

A. Continue with no change in operations.

B. retreat to optimum flight conditions for failure, continue to fly IFR to original IFR destination, do not declare an emergency but advise ATC of any required items (e.g., enroute time etc.).

C. retreat to optimum flight conditions for failure, discontinue IFR flight as soon as possible and select nearest suitable landing site. Interact with ATC as necessary but do not declare an emergency.

D. declare an emergency, terminate flight as soon as possible.

The ADEQUATE PERFORMANCE GUIDELINES predicated earlier (Table 4-1) apply to certain failure-mode operations also. Given the random nature (temporary, occasional occurences) of first-failures, it would appear that a somewhat higher workload would be expected or allowed for failure-mode flight. (This higher workload is probably acceptable because of decreased exposure and low probability of simultaneous occurence in conjunction with the less than ideal weather of the "nominal" bad IMC day described at the end of Section 2 of this report).

Although many varieties and definitions of failure modes exist, only one definition (formulated here for this report) is used. For the purposes of this report failure-mode operation is defined as that first-failure which allows the pilot to continue to fly after failure and complete the IFR mission without declaring an emergency. The failure must be adequately serious, such that, once safely on the ground, the pilot cannot dispatch on another IFR flight without first obtaining the needed repairs to the failed system(s).

Interpretation of Table 7-3 shows that for each specific case, the workload descriptor (for normal versus failure-mode operations) permits a maximum of only one paragraph shift in workload descriptor (greater effort and attention required to control aircraft in failure-mode while still achieving the adequate performance guidelines of Table 4-1).

In summary, when a failure-mode is identified as a failure-mode for which the pilot is expected to continue to the original destination (without asking for any priority ATC treatment), adequate performance guidelines are applied, but the allowable required workload is increased.

If a helicopter, being evaluated under either of the two evaluation patterns or under actual IFR conditions, reaches an "unusual flight condition", the result is a demonstration of non-compliance. That is, we can expect to have an occassional violation of the Performance Objectives of Table 4-1, but never an unusual attitude. (This comment excludes the immediate unrestrained response to hardovers.)

EXTREME WEATHER CONDITIONS AS A FAILURE MODE

In part, the failure mode was defined on page 7-11 as "a steady-state failure characterized by the various failed systems that affect the handling qualities." If extreme weather conditions and heavy turbulence are encountered, it is possible that the normal-mode handling qualities of an augmented helicopter could deteriorate sufficiently so that, in a sense, the extreme weather could cause the equivalent or same effects as a shift in descriptor due to failure.

For example, if, because of severe weather conditions and heavy turbulence, a two-piloted aircraft flying enroute (normal-mode) requires the pilot to provide CONSIDERABLE compensation (paragraph 1.3 in Tables 7-2 and 7-3) for the flight control task, he is operating at a descriptor level equivalent to that for the failure-mode of the base line. That is, for the nominal bad IMC day (predicated in this report as the norm), the two-pilot enroute case (for normal-mode operations) would allow a maximum of "MODERATE" pilot compensation (paragraph 1.2 in Tables 7-2 and 7-3). But now, because of the very bad weather and turbulence, he is required (and allowed) to increase his workload to provide CONSIDERABLE pilot compensation (paragraph 1.3) in order to achieve the "adequate performance" objectives of Table 4-1. Although nothing is failed, the pilot is providing the greater compensation in order to meet the same adequate performance objectives as before (but he is now operating at a more demanding workload level because of the very bad weather).

In the case of an unaugmented helicopter flying in extreme weather, pilot workload for the flight control task must necessarily increase to prevent degradation of man-machine performance. In the case of an augmented aircraft, turbulence can require the pilot to disengage certain functions of an autopilot (i.e. altitude-hold). It is also possible that an augmentation system may not have sufficient authority to adequately compensate for gust upsets; or may cause control inputs so rapid as to be unacceptable. Obviously, this would require the pilot to increase flight control workload to maintain aircraft attitude.

DISCUSSION ON WORKLOAD EVALUATION SYSTEM USAGE

The anticipated use of a workload evaluation system, requires that the evaluation pilots and other involved parties be sufficiently briefed so that everyone is using the same terminology, same task, etc. and talking about the same thing. This is usually best accomplished through the use of a briefing guide typical of that included in Reference 3.

For the workload evaluation system, Tables 7-2 and 7-3 may be utilized and applied during all flight check phases of the IFR certification process to provide guidance and determine compliance with the workload provisions of the regulations. An initial or preliminary determination can be accomplished by flying the helicopter through the two evaluation patterns detailed in Section 6 of this report (the "ENROUTE" and "APPROACH" IFR evaluation patterns of Figures 6-2 and 6-3). During the use of these patterns, the pilot would exert that workload level required to achieve the level of performance specified by the guidelines of Table 4-1. Preliminary determination of acceptability can then be made based upon a comparison of the observed flight control workload with the requirements and conditions of Table 7-3.

Stated another way, given the following:

- Specific levels of performance to be achieved,
- Specific SPECIAL CONDITIONS of Weather and Environment,
- Specific flight phase tasks to be flown (e.g., Approach, ILS-CAT I)
- Specific operational mode (e.g., normal-mode or failure-mode).

The aircrew will provide the:

1. Workload required (by the handling pilot) to satisfactorily accomplish the given task (e.g., Approach),

2. Workload required (by the handling pilot) to satisfactorily control the helicopter due to its particular flying qualities characteristics (i.e., provide the needed COMPENSATION),

3. Workload required (by the handling pilot for the one-pilot case or by the copilot for the two-pilot case) to accomplish all auxiliary tasks.

It is noted from the above, (for the given conditions and also providing that compliance has already been achieved on all other required IFR criteria) that if the aircrew can accomplish the above stated workload objectives with an acceptable workload level and a level of safety, the aircraft will PASS certification and if not, it will FAIL certification. The information contained in Tables 7-2 and 7-3 is formulated in such a way that judgments on items 1 and 2 above will determine the PASS/FAIL workload evaluation of the aircraft system and certification goal. Additional or final assessment of workload compliance would necessarily be accomplished during the required flight test activity in the air traffic control system under actual IFR day and night conditions (Interim Criteria, paragraph j), But the requirements of 7-3 would still be applied.

As an example of the use and interpretation of Tables 7-2 and 7-3, the following discussion for a one-pilot, normal-mode flight case is offered. Table 7-3 indicates that for the one-pilot, normal-mode case, paragraph 1.1 (Table 7-2) applies for the ENROUTE flight phases and paragraph 1.2 (Table 7-2) applies for the APPROACH flight phases.

Taking the ENROUTE case first (where heavy auxiliary task workload is predicated), the workload descriptor of Table 7-2, paragraph 1.1 states that, for the performance guidelines stipulated in Table 4-1, the pilot's flight control workload (pilot effort and attention required solely for the flight control task) shall not exceed the limits stated below:

1.1 Minimal pilot compensation. Control techniques are relaxed. Continual pilot involvement in short and long term flight control task.

Paragraph 1.1 means that the pilot is flying an aircraft where the amount of added flight control workload needed to make up for unwanted departures of the helicopter is minimal. His control techniques are relaxed and, although he is continually involved in the flight control task, the aircraft is easy to trim and control, does not respond readily to gusts and turbulence, and has minor or no cross-coupling effects. Although the pilot is continually involved in the flight control tasks, his inputs are sufficiently spaced or casual enough so that on occasion his attention may be required only at relatively long intervals to adjust the long term motion of the aircraft.

In order to achieve this to some degree, the aircraft may be inherently well stabilized (within its IFR tailored flight envelope) and/or it may be equipped with an ATTITUDE-SAS (or SCAS) system (providing additional angular damping and short term attitude stability) and/or is partially decoupled (e.g., a single-axis heading-hold feature provided by an autopilot type device). The helicopter may have, in addition to the above systems (or instead of), a multiple-axis ATTITUDE-HOLD system provided by a complete multiple-axis autopilot system.

For the one-pilot, normal-mode APPROACH case (where the auxiliary task workload is presumably lighter and subordinated during the final stages of the approach), the pilot's flight control workload shall not exceed the limits stated below (Table 7-2 and 7-3):

1.2 Moderate pilot compensation. Pilot is moderately involved in the flight control task and must continually correct the short term state of the aircraft.

The pilot is now flying the approach phases where he is closely controlling the helicopter. During close in portions of this task the pilot may be providing control inputs as frequently as every second or two in order to achieve the precision he desires. Also, since he can elect to subordinate or limit some of the auxiliary task workload because he is on the final approach, the pilot can allocate a larger proportion of his total workload capability to the flight control task. He therefore has the capability of flying an aircraft that requires more COMPENSATION than was permitted for the enroute case. That is, during the enroute case, he would like to remove his hands from the controls occasionally to navigate or copy a clearance and would like the aircraft to "fly-itself" a little, so that he can accomplish auxiliary tasks without too much concern and annoyance of correcting large upsets. His control techniques need to be relaxed. Whereas, in the approach case, he is more involved in achieving good tracking precision and allocates most of his workload capability to the flight control task and subordinates the auxiliary tasks for the time being.

It is worth noting that, in a general sense, the logic and use of the information in Tables 7-2 and 7-3 is the same as that offered earlier and discussed in an equivalent sense in the piechart discussions of Section 5 of this Report. That section of the report also provides an important premise on acceptable workload level versus aircrew manning that is consistent with the guidelines provided in Table 7-3 and is excerpted below:

"... the maximum allowable flight control workload level which can be safely accomplished by the Pilot-in-Command under single-pilot operations is <u>less than</u> the maximum allowable flight control workload level which can be safely accomplished by the Pilot-in-Command of dual-piloted aircraft.

As an example of the use and interpretation of the <u>TWO-PILOT</u>, normal-mode flight case, the following discussion is offered. Table 7-3 indicates that for this case, paragraph 1.2 predicates the maximum allowable flight control workload level for the ENROUTE flight phases and paragraph 1.3 applies for the APPROACH flight phases.

Discussing the ENROUTE phase first, the workload descriptor of Table 7-2, paragraph 1.2 states that for the performance guidelines stipulated in Table 4-1, the pilot's flight control workload (pilot effort and attention required solely for the flight control task) shall not exceed the limits stated below:

1.2 Moderate pilot compensation. Pilot is moderately involve in the flight control tasks and must continually correct the short term state of the aircraft.

Paragraph 1.2 means that the handling pilot is permitted to provide (up to) "moderate COMPENSATION". The effort and attention required for the flight control task can only involve him to a moderate degree. He is permitted to provide a workload level which is needed to continually correct the short term state of the helicopter. He may be flying an unaugmented vehicle or one that has a stabilizer bar but his control techniques will still require him to remain constantly in the flight control loop. The aircraft responds to gusts continually, he has considerable cross-coupling effects and the aircraft is somewhat difficult to trim accurately and quickly.

This case is in contrast to the ONE-PILOT, normal-mode enroute case but it is acceptable because, although the pilot is working harder than the comparable single-pilot case, he is still satisfied with the workload/performance level and has a full time copilot to aid him and accomplish all auxiliary tasks.

For the TWO-PILOT, normal-mode APPROACH case, the workload descriptor of TABLE 7-3, paragraph 1.3 states that for the performance guidelines stipulated in Table 4-1, the pilot's flight control workload (pilot effort and attention required solely for the flight control task) shall not exceed the limits stated below:

1.3 Considerable pilot compensation. Pilot is heavily involved in the flight control task. The pilot would not intentionally plan to encounter this level of effort for more than 5-10 minutes.

The pilot is now flying the approach phase where he is closely controlling the helicopter. He is quite busy and working pretty hard for this high-precision, high-performance task but is functioning satisfactorily and, with the copilots help, is well satisfied with the man/machine system and operation. However, the pilot is working considerably harder in this two-pilot Approach case as compared with the two-pilot Enroute case (and also as compared to the one-pilot, Approach case) but is fully satisfied with the situation since he knows he will be required to operate at this higher workload level for a relatively short time (say 5-10 minutes for the approach). Also, he has the aid and added assurance and safety of a fully capable copilot and is not being asked to exhibit exceptional skill, alertness and controllability. He is meeting his performance objectives and has confidence in the man/machine system. As far as meeting the IFR workload requirements of the Interim Criteria, this system will PASS.

With the same premises outlined in this section and logic used above, similar discussions and results can be noted for the failure-mode case for both two-pilot and one-pilot manning levels.

SUMMARY

The WORKLOAD DESCRIPTORS and ALLOWABLE FLIGHT CONTROL WORKLOAD LEVELS formulated in Section 7 of this report and shown in Tables 7-2 and 7-3 provide a basis for developing a candidate workload evaluation scheme to be utilized in the IFR certification process for helicopters. They offer structuring and formalization of important workload factors and considerations such as:

- flying qualities of the helicopter (e.g., stability, augmentation, displays, envelope tailoring, avionics, pilot COMPENSATION, etc.),
- aircrew manning level (e.g., one-pilot versus two-pilot),
- operational mode (e.g., normal-mode operational state versus failure-mode operational state),
- type of flight phase or task (e.g., Approach, Enroute, Missed Approach, etc.).

The workload evaluation system carefully considers the impact and importance of stated Performance Goals and Special Conditions of Weather and Environment. It is set up as a PASS/FAIL scheme that attempts to provide aid in standardizing the IFR certification techniques by defining the specific IFR piloting tasks, certification objectives commensurate with aircrew level and operational-mode (normal-state or failed-state) requirements. The intent of this type of workload/performance evaluation scheme is to establish absolute levels of acceptability or unacceptability (PASS/FAIL judgment) for all IFR helicopters similarly configured in the generic sense and not as a system to assess the relative "goodness or badness" of different helicopters and/or flight systems.

APPENDIX A

HANDLING QUALITIES: DEFINITIONS AND TERMINOLOGY

Many studies concerned with the evaluation of aircraft handling qualities and pilot performance/workload have been accomplished by numerous agencies and the most noteworthy and familiar efforts have been accomplished by Messrs. George Cooper of NASA Langley and Robert P. Harper of the CALSPAN Corporation, Buffalo, NY. In order to narrow and constrain some of the definitions and variables used in judgment on IFR helicopters, certain of their accepted and well recognized definitions and terminology are utilized here for convenience (excerpted verbatim from Reference 3). The terminology and ideas are useful in structuring certain of the other sections on Workload and Stability discussed in this report. Some of the most pertinent definitions needed in this study are shown below.

Handling Qualities - Those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role. (Note: The terms Handling Qualities and Flying Qualities are assumed to be equivalent.)

Mission - The composite of pilot-vehicle functions that must be performed to fulfill operational requirements. May be specified for a role, complete flight, flight phase, or flight subphase.

Flight Phase - A designated portion or segment of a complete flight. A mission phase. A flight phase may be represented by one or more separate tasks. Example: Takeoff, climb, cruise, descent, approach, and landing, (and emergency conditions).

Flight Subphase - That part of a flight phase having a single objective, and a single configuration or change in a configuration. Examples: Terminal area holding, glide slope capture, localizer capture, ILS tracking, wave-off.

Task - The actual work assigned a pilot to be performed in completion of or as representative of a designated flight segment.

Control - That part of a task which requires continuing actuation of the principal controls and use of the selectors as required. Examples: Movement between specified point, tracking, ILS or VOR tracking.

Auxiliary - That part of a task which involves the pilot in actions other than direct control of the aircraft. Examples: Navigation, communication monitoring, and selection of systems.

Workload - The integrated physical and mental effort required to perform a specified piloting task.

Physical - The effort expended by the pilot in moving or imposing forces on the controls during a specified piloting task.

Mental - Mental workload is at present not amenable to quantitative analysis by other than pilot evaluation, or indirect methods using physical workload (input) and the task performance measurements. An example would be the improvement associated with flight-director type displays which reduce the mental compensation normally required of the pilot.

Performance - The precision of control with respect to aircraft movement that a pilot is able to achieve in performing a task. (Pilot-vehicle performance is a measure of handling performance. Pilot performance is a measure of the manner of efficiency with which a pilot moves the principal controls in performing a task).

Compensation - The measure of additional pilot effort and attention required to maintain a given level of performance in the face of deficient vehicle characteristics.

Special Conditions - The special circumstances pertinent to the evaluation (i.e., aircraft environment and pilot stress). Examples: Special conditions of weather and environment, turbulence, wind shear, ceiling, visibility - night, etc. Pilot awareness, surprise, or distraction with respect to impending failure or disturbances.

Failure State - A steady-state failure characterized by the various failed systems that affect the handling qualities (or possibly the need for flying qualities). The dynamic effect of a failure is called a change of state and should be noted separately. Examples: Any failure resulting in loss of selected function. Engine failure, augmentation system, failure in stability, autothrottle, primary flight control system (power boost, electric stick, servo control feel, etc.) or secondary flight control system (trim, aerodynamic brake, etc.).

APPENDIX B

NARRATIVE SUMMARY OF EVENTS IN COMPOSITE HELICOPTER IFR FLIGHT PROFILE

Takeoff. According to Federal Aviation Regulations (FARs), helicopter takeoff requirements consist of visibility minima only for FAR Part 91 operators. However, helicopters which have been certified for IFR flight customarily have had limitations imposed via either Type Certificate (TC) or Supplemental Type Certificate (STC), establishing a "minimum approved IFR airspeed". Therefore, the takeoff profile for these helicopters consists of VFR hovertaxi and acceleration (while maintaining visual reference to the ground or runway lights) through translational lift until reaching a mandated "minimum approved IFR airspeed". The pilot may then initiate climbout and transition to Instrument Meteorological Conditions (IMC) at some predetermined airspeed.

IMC Climbout. Maintain a relatively high power setting for appropriate high rate of climb during IMC climbout on runway heading until reaching either circling minimums for departure point or an altitude prescribed in the Standard Instrument Departure (SID). Establish and maintain climb airspeed until desired altitude is reached, and adjust power for reduced rate of climb.

Standard Instrument Departure (SID). Climb on course in steady-state climb, contacting departure control. Intercept radial, navigate to point-in-space (intersection) and change course. Continue the climb as necessary, tracking radial that was used to identify the first intersection and intercept Victor airway at another intersection.

Climb Enroute. Continue a steady-state climb while tracking a Victor airway which is defined by a radial on a pretuned navaid. Possible reports of altitudes as they or reached or as requested by Air Traffic Control (ATC).

Cruise Enroute. Level aircraft and report level to ATC. Continue tracking course while executing level-off check of instruments and equipment, initiate fuel consumption check and doublecheck estimates for flight planning as appropriate. Cruise on course, identifying intersections and making position reports as necessary.

ATC Weather Avoidance Assistance. Obtain radar vectors from ATC to avoid storm cells and weather concentrations. Maintain altitude and adjust airspeed to turbulence penetration speed; comply with heading changes as directed by ATC. Brief passengers on weather and transmit Pilot

Reports (PIREPS) on observed and encountered weather conditions if appropriate. Receive ammended clearance from ATC and intercept Victor airway.

Climb Enroute. Comply with ATC altitude changes and report departing altitudes. Climb on course and make position reports as required. Level off, reporting level to ATC.

Descend Enroute. Comply with ATC altitude changes and report departing altitudes. Descend on course and make position reports as required. Level off, reporting level to ATC.

Hold Enroute. While cruising enroute (level, climbing or descending) receive holding instructions from ATC and copy. Review instructions and plan holding entry. Identify intersection; then enter pattern and time, turn, tune; reporting entry to ATC. Execute several patterns, adjusting outbound time as necessary to achieve required inbound leg time. Receive and copy ammended clearance while holding; then depart the holding pattern, reporting departure.

Standard Terminal Arrival Route (STAR). Depart from cruise course and navigate to point-in-space, identifying intersections along route, making position reports as required. Begin descending along route, report altitude changes (departing and level-off) to ATC and contact approach control when instructed.

ATC Radar Vectors to Final Approach Course (FAC). This begins the Initial Approach segment. Comply with heading changes requested by ATC, adjusting altitude as required. Retune navaids for approach, and review approach and missed approach procedures.

Hold at Intermediate Fix (IF) for Timed Approach. Enter and maintain holding pattern at Intermediate Approach Fix (holding narrative remains essentially the same as that for Hold Enroute). Update airfield weather data through Automated Terminal Information System (ATIS) or Flight Service Station (FSS). Brief copilot (if applicable) for approach and perform prelanding check. Retune navaids as appropriate. Descend in holding pattern as directed, reporting departing altitudes and level-offs. Adjust airspeed for approach and holding pattern legs for approach time; receive time check from ATC or FSS. Depart holding at appointed time, reporting departure, and intercept localizer course inbound.

Intermediate Approach Segment. Localizer (LOC) intercept out of holding starts this segment of the approach. Maintain altitude and track localizer course inbound, adjusting for local wind conditions.

Final Approach Segment. Glideslope (GS) intercept starts this segment of the approach. Establish rate of descent and begin tracking both GS and LOC simultaneously. Increase instrument scan rate and make continuous adjustments of power and attitude. Contact tower when instructed, maintain GS/LOC track, identify marker beacons. Continue descent to Decision Height (DH) and transition to VMC or execute missed approach, whichever is applicable.

Missed Approach Segment. The Missed Approach Point (MAP) is the DH for an ILS approach and starts this segment of the approach. An Inner Marker (IM) may be located at the MAP. Adjust collective to high power, changing from approximately 500 fpm descent to a high rate of climb. Maintain runway heading until reaching circling minimums. Contact tower, advise of missed approach, execute turn at circling minimums. Contact departure control, request desired clearance, and retune navaids. Intercept and track radial, adjusting power for reduced rate of climb; receive and copy ATC clearance. Identify intersection (normally missed approach limit), enter and maintain holding pattern, standing by for further clearance. Level off in holding and report level to ATC. Continue holding, recalculate fuel and time remaining if necessary and reveiw appropriate approach charts.

APPENDIX C

TIME LINE ANALYSIS ADDITIONAL DOCUMENTATION AND SAMPLE PROCEDURE

The specific tasks for each of the four critical flight segments identified in Section 3 were itemized, and are presented below. Although flight control tasks are addressed in general terms, the auxiliary tasks are sufficiently detailed to allow for recording the estimated time for completion of each task. This facilitated the quantification of the approximate portion of pilot's time/attention required for these tasks and, conversely, the approximate time/attention available for the flight control tasks. Other, less-consuming, auxiliary tasks which are readily time-shared require such minimal levels of effort that they may be executed easily while flying the aircraft, and were not included.

The Departure Segment is used to present a detailed example of the time line analysis methodology used to develop the data presented in Section 3. The complete procedure used to arrive at the workload percentages is presented in Figures C-1 through C-4.

Departure includes both the IMC Climbout and Standard Instrument Departure, and possibly initial portions of the Climb Enroute. In this situation, pilot first maintains a relatively high power setting for a high rate of climb, then commences to execute a SID or similar ATC clearance. While executing a departure clearance, pilots not infrequently receive amendments and must comply with course changes. The significance in changing or amending the pilot's initial clearance is not only in the navigation portion of auxiliary tasks, but also in the additional communications workload imposed on the pilot. Specific tasks follow:

1 - VMC/IMC transition (from takeoff to transition, including acceleration from zero).

2 - establish high power, high rate of climb, on runway heading.

3 - turn 90^{o} to new heading at circling minimums.

4 - (a) contact departure control; and (b) respond to "squawk and ident" instructions.

5 - receive and copy amended clearance.

6 - readback amended clearance.

7 - check map and retune navaids.

8 - turn 45^{o} to new heading, continuing climb.

9 - recalculate enroute times based on new routing.

10 - intercept and begin tracking new radial.

11 - report reaching altitude as requested, continue climbing.

12 - receive and respond to transmission from ATC, accept frequency change.

13 - retune comm radio.

14 - (a) contact next ATC facility, receive instructions for new squawk and later position report; and (b) respond to Squawk and ident" instructions.

15 - (a) cruise; then (b) identify intersection: retune nav radio, adjust Omni bearing selector (OBS).

Departure (Cont'd)

16 - (a) assess indications during climb; then (b) retune nav radio and readjust OBS.

17 - make tracking corrections and continue tracking radial.

18 - identify intersection: (retune nav radio, adjust OBS).

19 - turn 45^{o} to new heading to track new radial.

20 - (a) prepare; and (b) make postion report to ATC.

21 - (a) receive ATC frequency change with radar service terminated; and (b) reset transponder and retune comm radio.

22 - (a) contact approach control; and (b) make non-radar environment position report.

23 - level-off, continue tracking radial.

24 - (a) receive and copy further clearance; and (b) readback clearance.

xx - continue flight, cruise enroute.

Enroute includes those portions of the flight after the helicopter has reached the initially assigned cruising altitude, with departure procedure complete. It encompasses straight and level flight as well as climbs and descents enroute. The enroute portion of IFR flights can be quite cumbersome when travelling through high-density traffic areas such as Terminal Control Areas (TCAs) and the Northeast Corridor. Non-radar environment is assumed because the possibility exists of no radar coverage for some lower altitude flight situations, or a high workload at ATC facilities necessitating termination of some radar services to reduce that workload. Specific tasks follow:

1 - report arrival at altitude to ATC.

2 - level-off check (flight instruments, aircraft instruments, record fuel status).

3 - trim aircraft for cruise flight.

4 - track selected VOR radial.

5 - identify intersection (check map, tune/retune nav radio, assess indications, adjust/readjust OBS).

6 - adjust flight path to continue tracking as necessary.

7 - (a) prepare; and (b) make position report to ATC.

8 - receive and copy amended clearance from ATC.

9 - readback clearance.

10 - initiate climb enroute.

11 - recalculate flight plan for revised ETA.

12 - report adjusted ETA to ATC.

13 - level off at new altitude.

14 - report level to ATC.

15 - receive new ATC frequency.

16 - retune comm radio.

17 - (a) prepare position report; and (b) make initial contact to next controller.

Enroute (Cont'd)

18 - make full position report.

19 - continue tracking VOR radial.

20 - identify intersection (check map, tune/retune nav radio, assess indications adjust/readjust OBS).

21 - (a) prepare position report; and (b) make initial contact with ATC.

22 - make full position report.

23 - gather approach charts and place in usable location.

24 - review approach chart for destination (approach & missed approach).

25 - review approach chart for alternate (approach only).

Holding can be either published or unpublished. Typically, a published holding pattern will be reasonably simple no matter which direction the turns are. An example of this would be when ATC directs an IFR helicopter to hold at a prescribed intersection on an unpublished radial which requires an entry other than direct. This is the situation addressed here, beginning at cruise enroute prior to recieving holding instructions from ATC. Specific tasks follow:

1 - continue tracking VOR radial.

2 - respond to ATC originated contact.

3 - receive and copy holding instructions.

4 - read back instructions, request EFC time.

5 - receive and note EFC time, terminate comm with ATC.

6 - review holding instructions, plan entry.

7 - calculate effect of holding until EFC on ETA and fuel requirements.

8 - cruise, check position relative to described intersection (check map, tune/retune nav radio, assess indications, adjust/readjust OBS).

9 - cruise, then identify intersection (retune nav radio, readjust OBS).

10 - turn to outbound heading, note time.

11 - roll out of turn on outbound heading; retune nav radio, readjust OBS, note time, execute outbound leg.

12 - turn inbound, intercept radial, roll out, note time.

13 - adjust wind drift correction to track radial for inbound leg, identify intersection (retune nav radio, readjust OBS).

* REPEAT PREVIOUS FOUR (4) TASKS, adjust outbound times as required, adding following requirements.

14 - respond to ATC altitude change instructions("descend 1000 ft."), initiate descent in turn for 500 fpm vertical rate.

15 - outbound leg; retune nav radio, readjust OBS.

Holding (Cont'd)

16 - level off at new altitude during inbound turn, report level to ATC.

17 - receive and copy further clearance, read back clearance and continue flight.

xx - continue flight, cruise enroute.

Missed Approach is a high-stress situation which is not looked forward to eagerly by pilots. A more complex missed approach would typically consist of: changing from an established rate of descent to a high power climb on runway heading, climbing turn to a new heading, still with a considerable climb rate, intercept a VOR radial and climb to an intersection for holding, possibly with level off during the holding pattern. Throughout this flight segment, there are considerable auxiliary tasks incurred which cannot be put off easily. Specific tasks follow:

0 - conclude inability to make visual contact with runway at DH.

1 - initiate high power climb, maintain runway heading.

2 - report published missed to control tower, acknowledge instructions to contact departure control.

3 - retune comm radio.

4 - turn 45° to new heading.

5 - report published missed to departure control, prepare to copy clearance.

6 - receive and copy revised missed approach instructions.

7 - readback instructions, reset transponder.

8 - check map, retune nav radio, readjust OBS.

9 - assess indications, intercept radial with 45° climbing turn.

10 - reduce power for 500 fpm rate of climb, trim aircraft.

11 - apply necessary wind drift correction, and track radial.

12 - check position relative to described intersection (cruise, tune nav radio, adjust OBS, assess indications, retune nav radio, readjust OBS).

13 - cruise, plan entry, then identify intersection (retune nav radio, adjust OBS).

14 - climbing turn 180° to outbound heading, report entering holding to ATC, level off at assigned altitude in turn, report level to ATC, roll out on outbound heading.

Missed Approach (Cont'd)

15 - find approach chart for alternate, retune nav radio/readjust OBS for holding (outbound leg).

16 - begin review approach chart for approach and missed approach during inbound turn.

17 - track inbound leg, identify intersection.

18 - 180° outbound turn, continue review of approach charts.

19 - outbound leg, finish review of approach charts.

20 - inbound turn, complete review of approach charts.

21 - inbound leg, identify intersection.

* REPEAT HOLDING SEQUENCE PER TASKS 10-13 , HOLDING SEGMENT.

SAMPLE PROCEDURE, DEPARTURE SEGMENT

Time required to complete each task was recorded for the four flight segments of interest. The tasks itemized for Departure Segment are shown here with the times allocated. A graphic presentation is made in Figure C-1, with an alternate presentation in Figure C-2. Figures C-3 and C-4 show new workload computations and final presentation of time line analysis results that were developed.

TIME ALLOCATIONS (Departure Segment)

TIME (Seconds)	
30	1 - VMC/IMC transition (from takeoff to transition, including acceleration from zero).
10	2 - establish high power, high rate of climb, on runway heading.
30	3 - turn 90° to new heading at circling minimums.
10/10	4 - (a) contact departure control; and (b) respond to "squawk and ident" instructions.
15	5 - receive and copy amended clearance.
15	6 - readback amended clearance.
12	7 - check map and retune navaids.
15	8 - turn 45° to new heading, continuing climb.
55	9 - recalculate enroute times based on new routing.
60	10 - intercept and begin tracking new radial.
15	11 - report reaching altitude as requested, continue climbing.
15	12 - receive and respond to transmission from ATC, accept frequency change.
10	13 - retune comm radio.

TIME ALLOCATIONS (Departure Segment) (Cont'd)

TIME (Seconds)	
15/10	14 - (a) contact next ATC facility, receive instructions for new squawk and later position report; and (b) respond to Squawk and ident" instructions.
15/12	15 - (a) cruise; then (b) identify intersection: retune nav radio, adjust Omni bearing selector (OBS).
15/12	16 - (a) assess indications during climb; then (b) retune nav radio and readjust OBS.
60	17 - make tracking corrections and continue tracking radial.
15/12	13 - identify intersection: (retune nav radio, adjust OBS).
15	19 - turn 45° to new heading to track new radial.
9/15	20 - (a) prepare; and (b) make postion report to ATC.
15/10	21 - (a) receive ATC frequency change with radar service terminated; and (b) reset transponder and retune comm radio.
10/15	22 - (a) contact approach control; and (b) make non-radar environment position report.
15	23 - level-off, continue tracking radial.
15/10	24 - (a) receive and copy further clearance; and (b) readback clearance.
	xx - continue flight, cruise enroute.

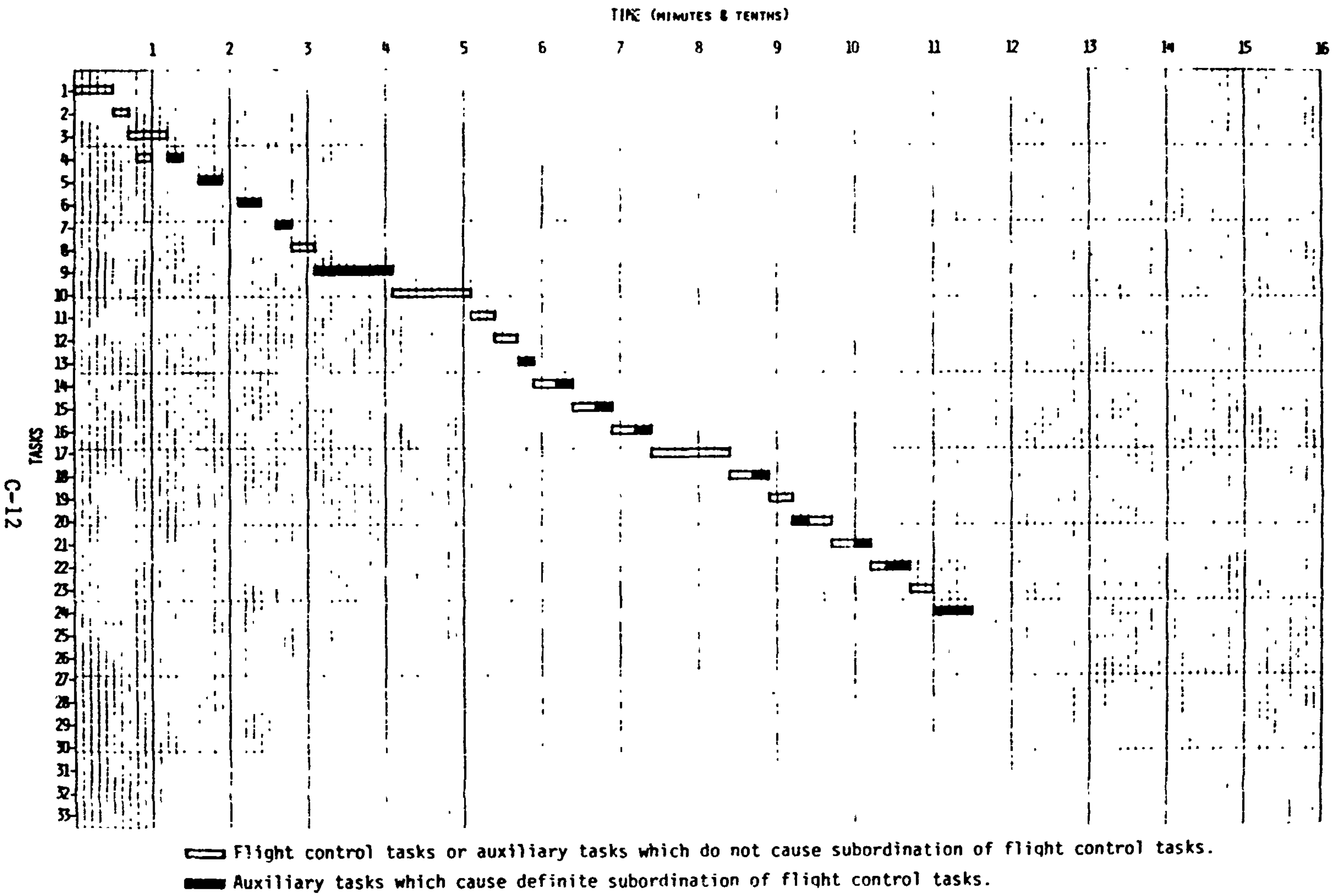
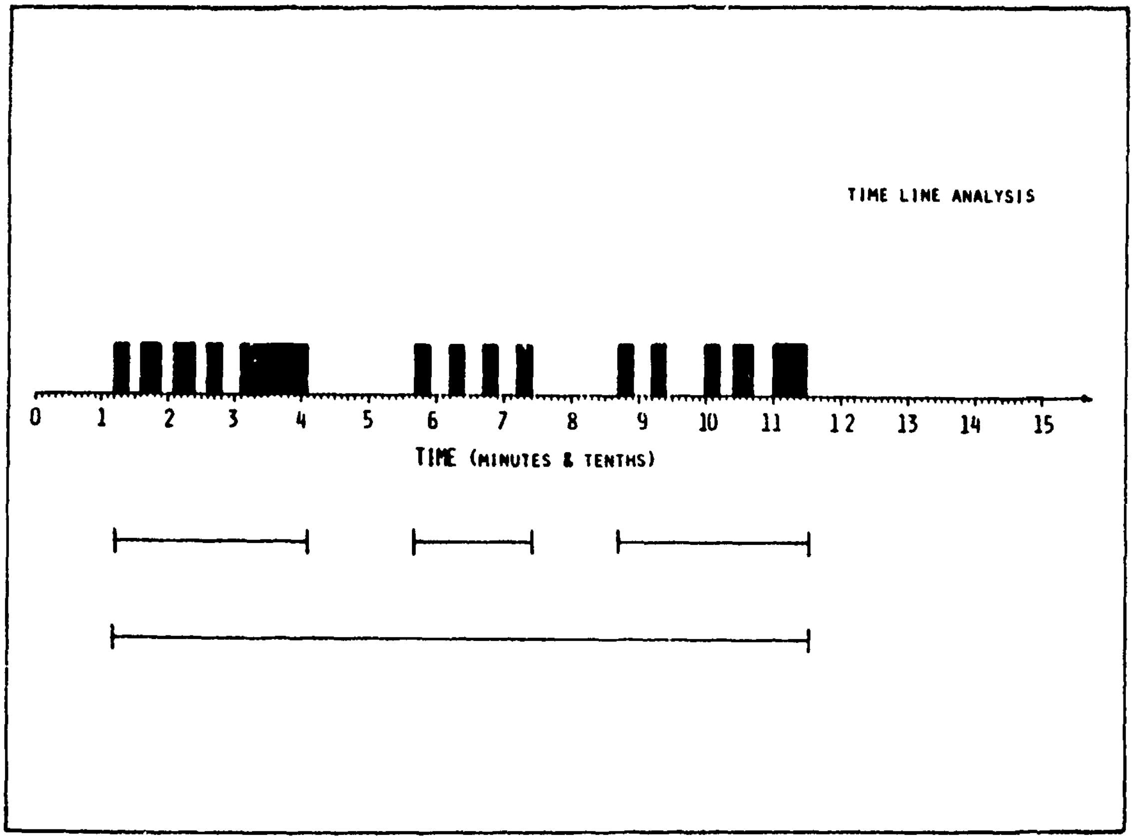


Figure C-1. Graphic Presentation of Time Allocations, Departure Segment.



*NOTE: (1) Only shaded tasks from Figure C-1 are used; presenting those auxiliary tasks which cause definite subordination of flight control tasks (i.e., pilot out of the flight control loop).
(2) Periods of peak activity isolated and identified.

Figure C-2. Alternate Presentation of Time Line Analysis, Departure Segment.

(a) Period	(b) Start-Stop	(c) Total Time	(d) Sum of Aux. Task Time	(d÷c)X100 Aux. Task Workload %
1.	1.2 - 4.1	2.9	2.0	68.97
2.	5.7 - 7.4	1.7	.8	47.10
3.	8.7 -11.5	2.8	1.4	50.00
4.	1.2 -11.5	10.3	4.2	40.78

Figure C-3. Computation of Workload for Time Line Analysis, Departure Segment.

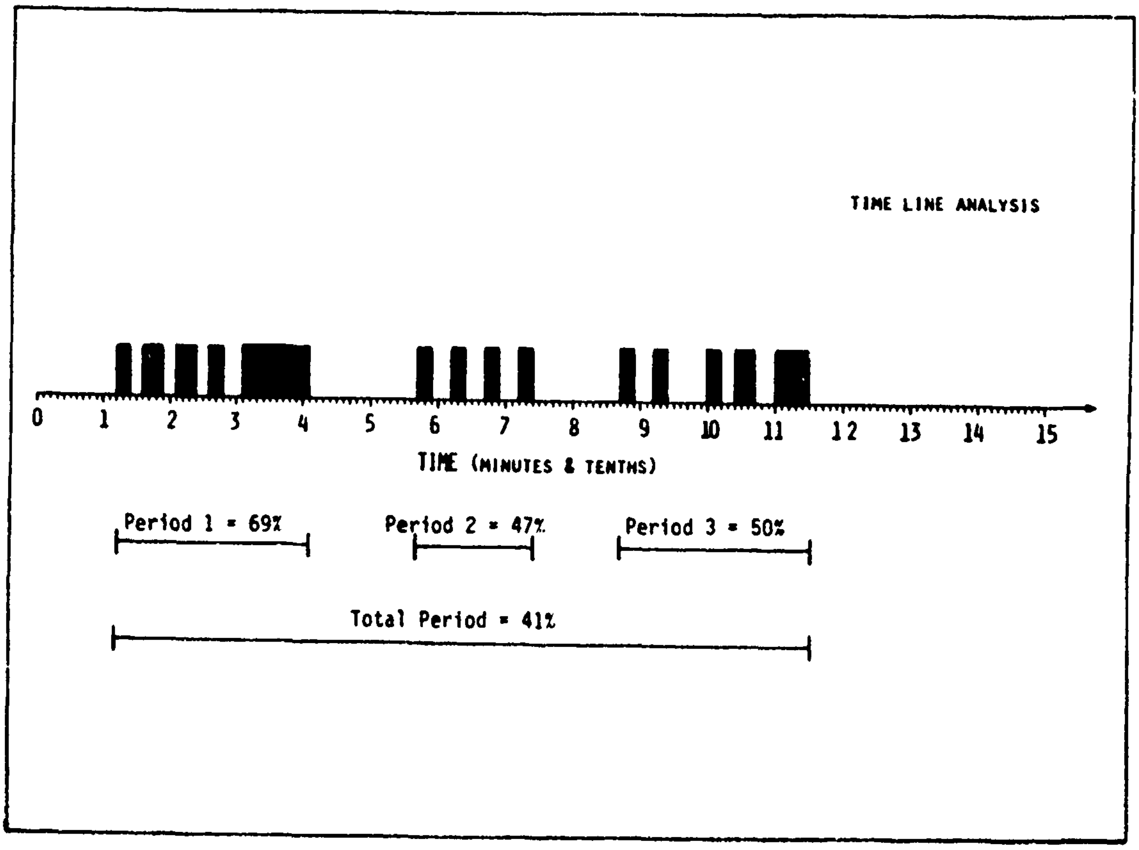


Figure C-4. Results of Time Line Analysis, Departure Segment.

APPENDIX D

REFERENCE TABLES AND OTHER SUPPORTIVE DOCUMENTS

This Appendix contains additional supportive documents and reference tables which expand definitions and conditions used in this report. They have been referenced appropriately in the text of the report.

TABLE D-1

TURBULENCE CRITERIA, DEFINITIONS
(Reference 6)

TURBULENCE REPORTING CRITERIA TABLE

Intensity	*Aircraft Reaction*	*Reaction Inside Aircraft*	*Reporting Term Definition*
LIGHT	Turbulence that momentarily causes slight, erratic changes in altitude and/or attitude (pitch, roll, yaw). Report as *Light Turbulence*;* or Turbulence that causes slight, rapid and somewhat rhythmic bumpiness without appreciable changes in altitude or attitude. Report as *Light Chop*.	Occupants may feel a slight strain against seat belts or shoulder straps. Unsecured objects may be displaced slightly. Food service may be conducted and little or no difficulty is encountered in walking.	Occasional—Less than 1/3 of the time. Intermittent—1/3 to 2/3. Continuous—More than 2/3.
MODERATE	Turbulence that is similar to Light Turbulence but of greater intensity. Changes in altitude and/or attitude occur but the aircraft remains in positive control at all times. It usually causes variations in indicated airspeed. Report as *Moderate Turbulence*;* or Turbulence that is similar to Light Chop but of greater intensity. It causes rapid bumps or jolts without appreciable changes in aircraft altitude or attitude. Report as *Moderate Chop*.	Occupants feel definite strains against seat belts or shoulder straps. Unsecured objects are dislodged. Food service and walking are difficult.	Note—Pilots should report location(s), time (GMT), intensity, whether in or near clouds, altitude, type of aircraft and, when applicable, duration of turbulence. Duration may be based on time between two locations or over a single location. All locations should be readily identifiable. Example: a. Over Omaha, 1232Z, Moderate Turbulence, in cloud, Flight Level 310, B707. b. From 50 miles south of Albuquerque to 30 miles north of Phoenix, 1210Z to 1250Z, occasional Moderate Chop, Flight Level 330, DC8.
SEVERE	Turbulence that causes large, abrupt changes in altitude and/or attitude. It usualy causes large variations in indicated airspeed. Aircraft may be momentarily out of control. Report as *Severe Turbulence*.*	Occupants are forced violently against seat belts or shoulder straps. Unsecured objects are tossed about. Food service and walking are impossible.	
EXTREME	Turbulence in which the aircraft is violently tossed about and is practically impossible to control. It may cause structural damage. Report as *Extreme Turbulence*.*		

* High level turbulence (normally above 15,000 feet ASL) not associated with cumuliform cloudiness, including thunderstorms, should be reported as CAT (clear air turbulence) preceded by the appropriate intensity, or light or moderate chop.

TABLE D-2

ERROR DEFINITIONS FOR TRACKING AND NAVIGATION PERFORMANCE

Advisory Circular 90-45A on Approval of Area Navigation Systems for Use in the NAS contains an Appendix entitled Sources of Navigation System Error. In Appendix C of that Advisory Circular, Section 4 (Sources of Error), contains a subparagraph (a,3) that lists a number of commonly used definitions on horizontal tracking error. They are:

- Flight technical error refers to the accuracy with which the pilot controls the aircraft as measured by his success in causing the indicated aircraft position to match the indicated command or desired position on the display.

- Manual insertion errors are due to the human interface with the control and display units that affect the performance of an RNAV operation. The resulting error causes a deviation from the defined RNAV flight plan. These errors are usually recognized and corrected before developing in magnitude to a point where they may be considered blunders. However, "manual" errors also include undetected errors such as inaccuracies in track setting and in setting waypoint bearing information in some types of systems.

- Blunder errors are gross errors in human judgment or attentiveness that cause the pilot to stray significantly from his area navigation flight plan, and are not included in the area navigation system error budget. Blunder tendency is, however, an important system design consideration.

- Pilotage error will vary widely, depending on such factors as pilot experience, pilot workload, fatigue, and motivation. Equipment design and ambient environment variables also affect pilotage directly and measurably, such as:

  - Processing of the basic display inputs (i.e., smoothing and quickening), whether or not heading is presented integrally with position and/or command guidance indications, display scale factors, numerous display configuration variables, aircraft control dynamics, air turbulence, and many more. Strictly speaking, with autopilot coupling, "flight technical error" becomes "autopilot error". These factors must be taken into account in arriving at empirical values for pilotage contribution to system use accuracy.

GLOSSARY - GENERAL DEFINITIONS

AIR TRAFFIC CONTROL. Service operated by appropriate authority to promote the safe, orderly, and expeditious flow of air traffic.

AREA NAVIGATION (RNAV). Method of navigation that permits aircraft operations on any desired course within the coverage of station-referenced navigation signals or within the limits of self-contained system capability.

AUTOROTATION. Rotorcraft flight condition in which the lifting rotor is driven entirely by action of the air when the rotorcraft is in motion.

CATEGORY II OPERATION. With respect to the operation of aircraft, a straight-in ILS approach to the runway of an airport under a Category II ILS instrument approach procedure issued by the Administrator or other appropriate authority.

CEILING. Height above the earth's surface of the lowest layer of clouds or obscuring phenomena that is reported as "broken", "overcast", or "obscuration", and not classified as "thin" or "partial".

DECISION HEIGHT. With respect to the operation of aircraft, the height at which a decision must be made, during an ILS or PAR instrument approach, to either continue the approach or to execute a missed approach.

VISIBILITY, FLIGHT. Average forward horizontal distance, from the cockpit of an aircraft in flight, at which prominent unlighted objects may be seen and identified by day and prominent lighted objects may be seen and identified by night.

VISIBILITY, GROUND. Prevailing horizontal visibility near the earth's surface as reported by the United States National Weather Service or an accredited observer.

HELIPORT. An area of land, water, or structure used or intended to be used for the landing and takeoff of helicopters.

IFR CONDITIONS. Weather conditions below the minimum for flight under visual flight rules.

IFR OVER-THE-TOP. With respect to the operation of aircraft, means the operation of an aircraft over-the-top on an IFR flight plan when cleared by air traffic control to maintain "VFR conditions on top".

MINIMUM DESCENT ALTITUDE. The lowest altitude, expressed in feet above mean sea level, to which descent is authorized on final approach or during circle-to-land maneuvering in execution of a standard instrument approach procedure, where no electronic glide slope is provided.

NON-PRECISION APPROACH PROCEDURE. A standard instrument approach procedure in which no electronic glide slope is provided.

OVER-THE-TOP. Above the layer of clouds or other obscuring phenomena forming the ceiling.

PILOTAGE. Means navigation by visual reference to landmarks.

PRECISION APPROACH PROCEDURE. A standard instrument approach procedure in which an electronic glide slope is provided, such as ILS and PAR.

RNAV WAY POINT (W/P). Predetermined geographical position used for route or instrument approach definition or progress reporting purposes that is defined relative to a VORTAC station position.

ROUTE SEGMENT. Part of a route, i.e. each end of that part identified by -

(1) a continental or insular geographical location; or

(2) a point at which a definite radio fix can be established.

VFR OVER-THE-TOP. With respect to the operation of aircraft, means the operation of an aircraft over-the-top under VFR when it is not being operated on an IFR flight plan.

REFERENCES

1. Traybar, J.J., Green, D.L. DeLucien, A.G., REVIEW OF AIRWORTHINESS STANDARDS FOR CERTIFICATION OF HELICOPTERS FOR INSTRUMENT FLIGHT RULES (IFR) OPERATION, FAA-RD-78-157, Pacer Systems, Inc. Arlington, Virginia, Prepared for U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C., February 1979.

2. ANON: Interim Criteria, HELICOPTER INSTRUMENT FLIGHT RULES CERTIFICATION, (Version utilized for IFR certification prior to 1979) Federal Aviation Administration, Department of Transportation, Washington, D.C.

3. Cooper, George E., and Harper Jr., Robert P., THE USE OF PILOT RATING IN THE EVALUATION OF AIRCRAFT HANDLING QUALITIES, N69 22539, NASA TN D-5153, National Aeronautics and Space Administration, Washington, D.C., April 1969.

4. Gasperian, Richard G., HELICOPTER PILOT WORKLOAD EVALUATION, AD A057666, IFC TR 78-2, Research and Development Branch, USAF Instrument Flight Center, Texas, 1978.

5. Geiselhart, Richard, CREW FACTORS, WORKLOAD AND PERFORMANCE, Air Line Pilots Association, Washington, D.C., Presented at the Proceedings of the Symposium on Man-System Interface: Advances in Workload Study, Washington D.C., July 31 and August 1, 1978.

6. ANON: AIRMAN'S INFORMATION MANUAL, Basic Flight Information and ATC Procedures, TAD 443.1, U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C., August 1976.

7. Burgin, Robert E., THE MISSED APPROACH, Journal of ATC, September 1978.

8. ANON: INSTRUMENT FLYING HANDBOOK, AC 61-27B, Department of Transportation, Federal Avistion Administration, Washington, D.C., 1971.

9. ANON: INSTRUMENT FLYING AND NAVIGATION FOR ARMY AVIATORS, FM 1-5, Headquarters, Department of the Army, Washington, D.C., March 1976.

10. ANON: INSTRUMENT INSTRUCTOR AND MANEUVER GUIDE, United States Army Aviation School, Fort Rucker, Alabama, August 1971.

11. ANON: Unites States Standard for TERMINAL INSTRUMENT PROCEDURES (TERPS), Department of Transportation, Federal Aviation Administration, Washington, D.C., July 1976.

12. Wierwille, Walter W. and Williges, Robert C., SURVEY AND ANALYSIS OF OPERATOR WORKLOAD ASSESSMENT TECHNIQUES, S-78-101, Systemetrics, Inc., Blacksburg, Virginia, Prepared for Navairsyscom Code 340F, September 1978.

13. Wickens, Cnristopher, BRAIN ELECTRICAL ACTIVITY AS AN INDEX OF WORKLOAD, University of Illinois, Presented at Proceedings of the Symposium on Man-System Interface: Advanced in Workload Study, Air Line Pilots Association, Washington, D.C., July 31 and August 1, 1978.

14. ANON: Flight Test Guide, INSTRUMENT PILOT HELICOPTER, AC 61-64, Department of Transportation, Federal Aviation, Administration, 1973.

15. ANON: HEARINGS before a Subcommittee of the Committee on Appropriations, United States Senate, Ninety-Fifth Congress, Second Session. Department of Transportation, Certification of Transport Aircraft on pages 1134-1136, U.S. Government Printing Office, Washington, D.C., 1978.